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PHYSICS.—*Meteorological factors affecting spread of radioactivity from nuclear bombs.*[1]

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The fission products from a nuclear explosion are harmless until brought into man's environment or food. The dispersal from test site takes place largely through atmospheric transport. The problem, however, is more than the application of the winds to carry the particulate debris; turbulent diffusion and precipitation, for example, also play important roles.

In treating the entire radioactive fallout spectrum, it is convenient to divide the particulate fallout into three categories; first, that which deposits out in the first day, or less. This is designated as local fallout since in this short time the horizontal displacement cannot have been very great. The second class is deposited between about 1 day and a few months. For lack of a better word, it will be termed intermediate fallout. Finally, the fallout delivered beyond a few months is called delayed fallout. Because the particles are injected into the stratosphere and found over much of the globe, it is also referred to as "world-wide stratospheric fallout."

It is the purpose of this discussion to point out the meteorological considerations which account for atmospheric transport of all types of debris. Remarks on local and intermediate ranges will be brief, while those pertaining to delayed fallout, will be more extensive.

LOCAL FALLOUT

The particles of local fallout settle mainly because of their weight. Given their size, shape, and specific gravity, it is possible to predict the fall velocity.

However, even in the absence of exact information on their characteristics, it is possible to produce useful results as to where and when particles will reach the ground. This is because the relative time of fall as a function of altitude, the important element, is insensitive to the particle's physical properties.

There are at least two other processes which produce a downward flux of particles in the atmosphere. First, vertical mixing acting upon a cloud of particles at upper altitudes will transfer some of these to lower altitudes. The magnitude of usual tropospheric vertical eddy speeds is thought to be of the order of a few tenths to a few miles per hour. It is likely that particles which have settling speeds of a tenth to a hundreth of the eddy velocity will have their vertical component of motion controlled mainly by atmospheric turbulence. Those with fall velocities equal to or greater than a few miles per hour will descend mainly because of gravitational settling. The gravitational effect for a spherical particle of specific gravity of 2.5 takes over between about 50 and 80 microns in diameter. Most particles in the heavy local fallout descend at rates corresponding to sizes over 50 microns in diameter.

A second means of downward transfer of the particles occurs by precipitation. Insofar as possible, nuclear tests by the United States are conducted in the absence of naturally-occurring precipitation. However, in the Pacific Proving Grounds, it is likely that the huge amount of moisture entrained

[1] Presented at the Washington Academy of Sciences Fall Symposium, Washington, D. C., November 15, 1956.

by the rising fireball condenses upon cooling and that some downward transfer of the particles results from scavenging of falling precipitation.

The horizontal motion of the falling particles results primarily from the action of winds which are observed by conventional wind measuring equipment. The procedures for utilizing winds for the determination of fallout areas are entirely straight-forward. The falling particle is transported horizontally by the wind in a layer depending upon its stay in the layer before settling to the next lower one. The summation of the horizontal displacements ends with the ground deposition of the particle.

In addition to transport by the usually observed winds, there is a certain amount of lateral dispersion because of horizontal turbulence in the atmosphere. Experience suggests that in most cases, the spread of falling particles by the average winds so greatly exceed the spread due to small-scale turbulence that the diffusive spread is usually ignored.

In the prediction of local fallout radiation gamma intensities from the ground, it is necessary to know not only the winds and physical characteristics of the falling particles, but also the amount of radioactivity as a function of particle size and altitude. This latter information is essentially non-meteorological and will not be dealt with at this time. An example of the final result of the application of meteorological winds to a model of radioactivity as a function of particle size and altitude is presented in the first few figures.

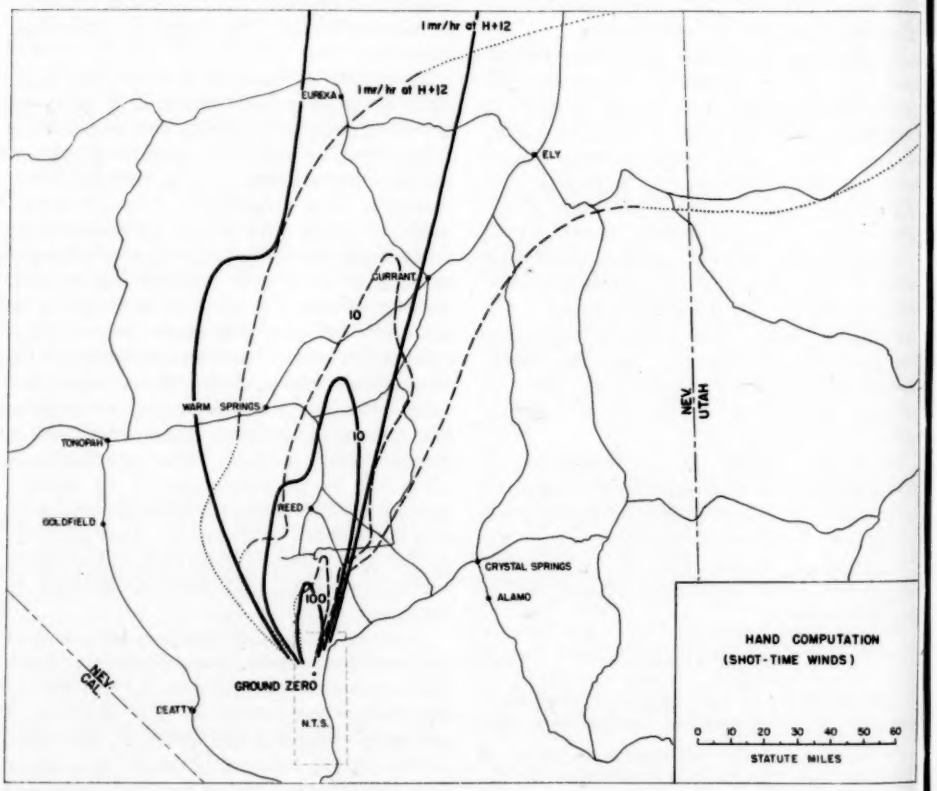

FIG. 1.

The first figure shows the actual and predicted isolines of gamma activity in milliroentgens per hour referred to twelve hours. The light dashes are the observed field and were derived from ground monitoring along various roads around the Nevada Test Site. The heavy lines are the predicted fallout pattern using a Weather Bureau model of cloud radioactivity. On this picture, the winds measured near the explosion place and time the bomb went off, which were mainly from south to north, were assumed to carry particles at all later times and places. It is evident that this prediction fails to reflect the bending of the pattern to the east in northern Nevada. This static wind picture is the kind used in most fallout forecasts. The next figure (2) contains a computed fallout pattern, as the heavy lines, which includes the best estimate of the change of the wind in time and in space. It is evident that incorporation of the changing winds provides a better verification. These calculated fallout patterns are typical of most cases which have been attempted using meteorological data.

INTERMEDIATE FALLOUT

After most of the particles whose size are large enough to have a significant fall velocity have been removed from the atmosphere, the remaining particles are part of either the intermediate or delayed fallout.

For weapons which have been fired at the Nevada Test Site, the intermediate fallout originates in the troposphere since the nuclear cloud tops rarely penetrated the tropopause. However, for high-yield detonations, the intermediate fallout may originate either from tropospheric or stratospheric

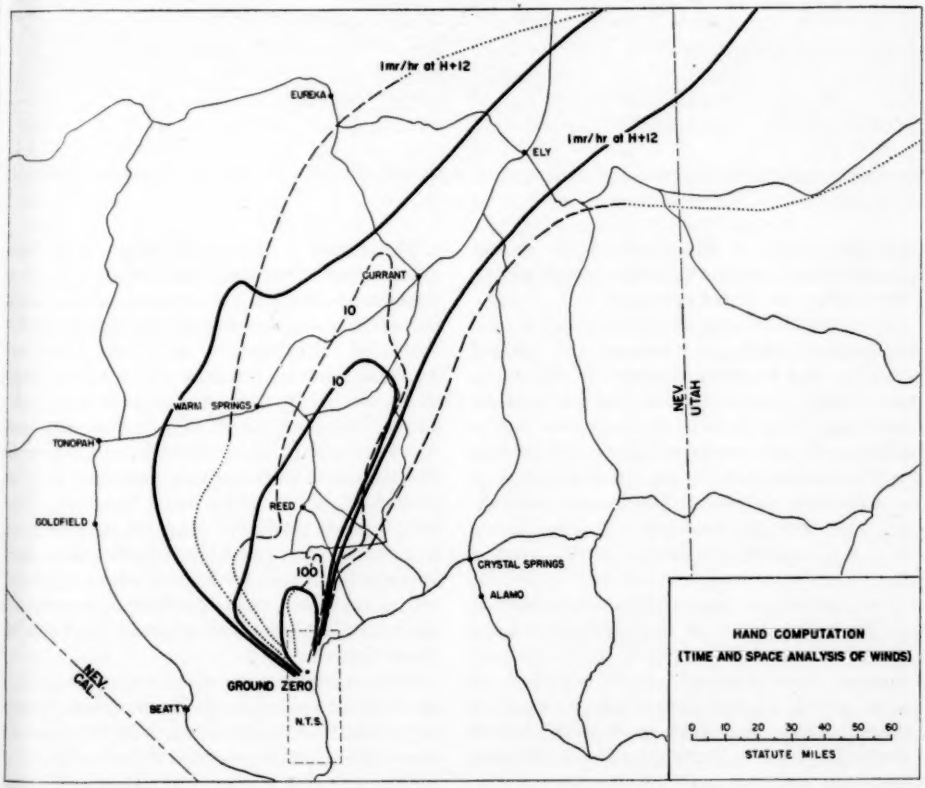

FIG. 2.

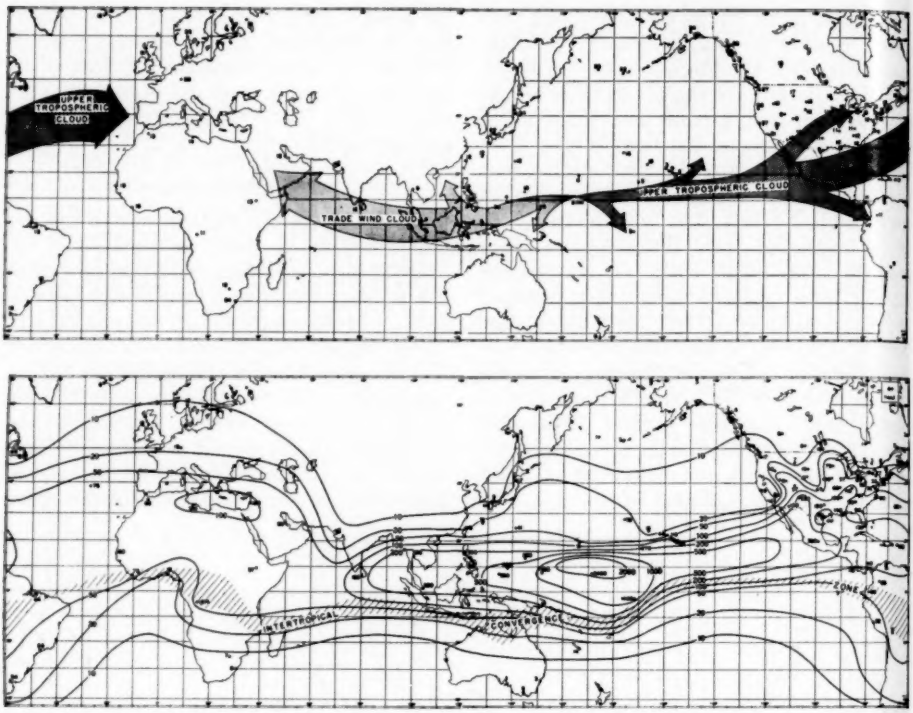

FIG. 3.

material, and, at the moment, it is not possible to say with confidence which source contributes the larger fraction.

It is characteristic of the motions in the atmosphere that air masses are carried zonally, that is, around circles of latitudes, much more rapidly than in the north-south direction. This is true both in the troposphere and stratosphere. The result of this meteorological fact is the predominance of intermediate fallout in the same latitude band as the test locations. In Fig. 3, the 35-day cumulative fallout from CASTLE BRAVO is shown as a series of isolines on the lower part of the figure. The upper portion of the figure shows as the shaded area the regions of the globe which, from meteorological considerations, were expected to have fallout in the first week or so. It is evident that the band of highest fallout circles the earth in the tropics of the northern hemisphere with only occasional north-south excursions.

The removal of intermediate range particles from the atmosphere during dry weather is assisted by vertical eddies near the earth's surface and by interception by obstacles. However, it is likely that an important fraction is removed by precipitation scavenging. It has been found, for example, following most of our Nevada test operations, that on days with rain, there is 10 times more radioactivity deposited on the ground than on days with no rain. The particles are probably large enough so that scavenging by inertial effects are still important as will be shown later. That is, the small radioactive particles, because of their inertia cannot escape from the path of the falling raindrop.

The budgeting of the fraction of radioactivity deposited in the intermediate range as well as that in the delayed fallout is quite uncertain. Careful analysis of the world-wide fallout network of the U. S. Atomic Energy Commission after the IVY and CASTLE test

series suggests that between 1 and 5 percent of the fission products which were formed fell out between about 1 and 30 days after each test operation. The same numbers for the intermediate fallout from the Nevada tests amounts to perhaps 25 percent. In the latter case, the amount of the close-in fallout is known quite exactly and, since there is no delayed fallout, we can add the local and intermediate fallout together to obtain the total. The result shows that something of the order of 65 percent of the radioactivity is still unaccounted for in the Nevada tests. It is possible that the local fallout, in this case, has been underestimated but this is unlikely. The more reasonable explanation is given in terms of our inability to accurately measure the true removal of particles from the atmosphere with simple devices. The estimate just mentioned is based on the measurement of fallout on gummed films exposed horizontally. Even if gummed papers are 100 percent efficient (and they are believed to be about 70 percent efficient for gross fission products now under discussion), it fails to detect radioactive particles removed by vertical surfaces. The Naval Research Laboratory in Washington, D. C., has reported an amount of radioactivity on a vertically exposed piece of cheesecloth equal to that deposited on the ground for the same time interval and area. Other experiments confirm the fact that the particles in the intermediate range are collected by other than horizontally exposed face-up surfaces. The question which is still unanswered, however, is how much more is removed than that observed by the gummed film network.

Thus, the cumulative contribution of the intermediate fallout and the delayed fallout over that portion of the world lying in the belt surrounding the nuclear proving grounds is still somewhat questionable. When soil samples are collected, say over the U. S., which have integrated all fallout since the atomic age, questions may be raised concerning the apportionment of the fallout.

Although, on the average, the bulk of the radioactivity in the intermediate range lies in a belt surrounding the latitude of the test site, there can be anomalous situations which will spread the debris over a very large north-south range or carry the entire nuclear cloud in fact to a new and distant latitude for zonal transport there.

DELAYED FALLOUT

Since the particulate debris which is located in the troposphere can be shown to be removed within a matter of weeks or months even from delayed fallout, it follows that delayed fallout must be stored somewhere. Aircraft sampling and balloon flights have clearly established that the stratosphere is the storage region for delayed fallout. It can also be deduced that, since the particles take longer than a few months to fall out of the atmosphere, their size must be exceedingly small and it would be estimated that they are no larger than 1 micron and probably well below 0.1 micron in diameter. However, despite this apparent smallness in size, we have no positive proof, at this point, that gravitational settling does not contribute to the transfer of radioactive particles from the stratosphere into the troposphere, and, in fact, there is the slightest suggestion that gravitational settling may even be important.

It is perhaps worthwhile at this point to review the questions which can be asked of the meterorologist with respect to delayed fallout. First, how fast is the particulate debris leaving the stratosphere, and second, where will it come out.

In order to make a prediction of contamination, it is essential to know the source of the pollutants. It is not known from the high altitude measurements exactly where the debris is located in the stratosphere. The next figure (4) shows some of the reasoning in trying to determine even the initial vertical distribution. To the left, we see a drawing of a nuclear cloud with the familiar stem and mushroom. In this hypothetical high-yield explosion, the entire mushroom has been placed in the stratosphere above the tropopause. To the right, we see, as the dashed line, the profile of the visible part of the mushroom. If one assumes that extreme turbulence exists in this cloud so that it is thoroughly mixed, then at every point the amount of radioactivity per gram of air is constant. Since the mass of air per unit volume or air density decreases with height,

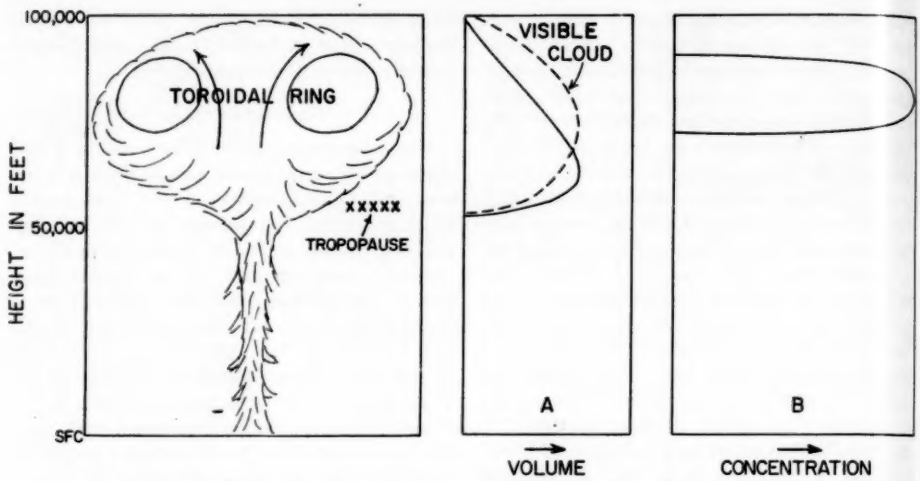

FIG. 4.—Schematic vertical distributions of small particles in nuclear cloud.

there would be more radioactivity near the bottom of the cloud as illustrated by the adjacent solid line. On the other hand, it can be argued that the small particles remain with the fireball and that the fireball becomes the torroidal ring present with most, if not all, nuclear explosions. If this is the case, then it is possible that the radioactivity is distributed according to profile B.

The geographical locale for the debris is less uncertain. In Fig. 5, a vertical cross section from pole to pole is shown with the approximate latitudes of high-yield explosions indicated at the upper border. As previously noted, the stratosphere is the reservoir for the small particles of the de-

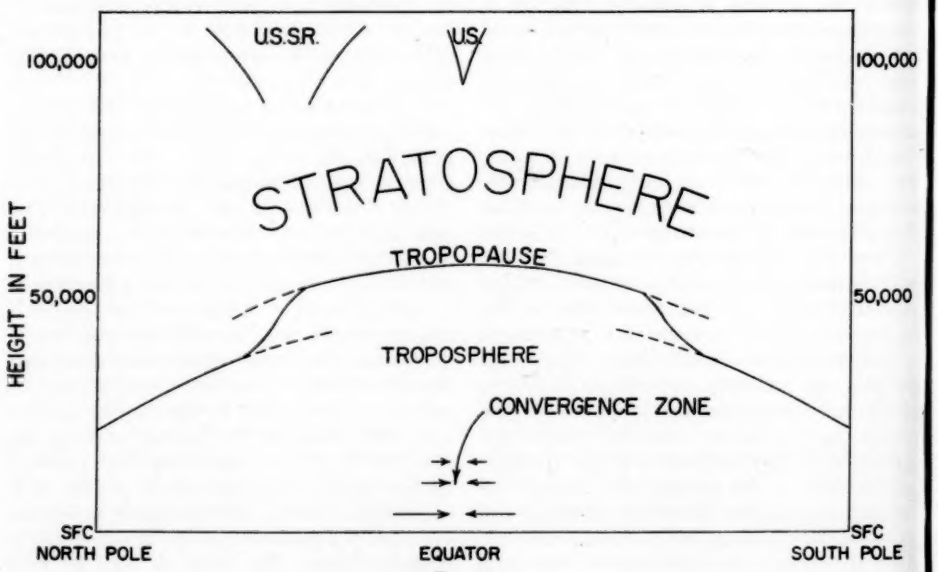

FIG. 5.

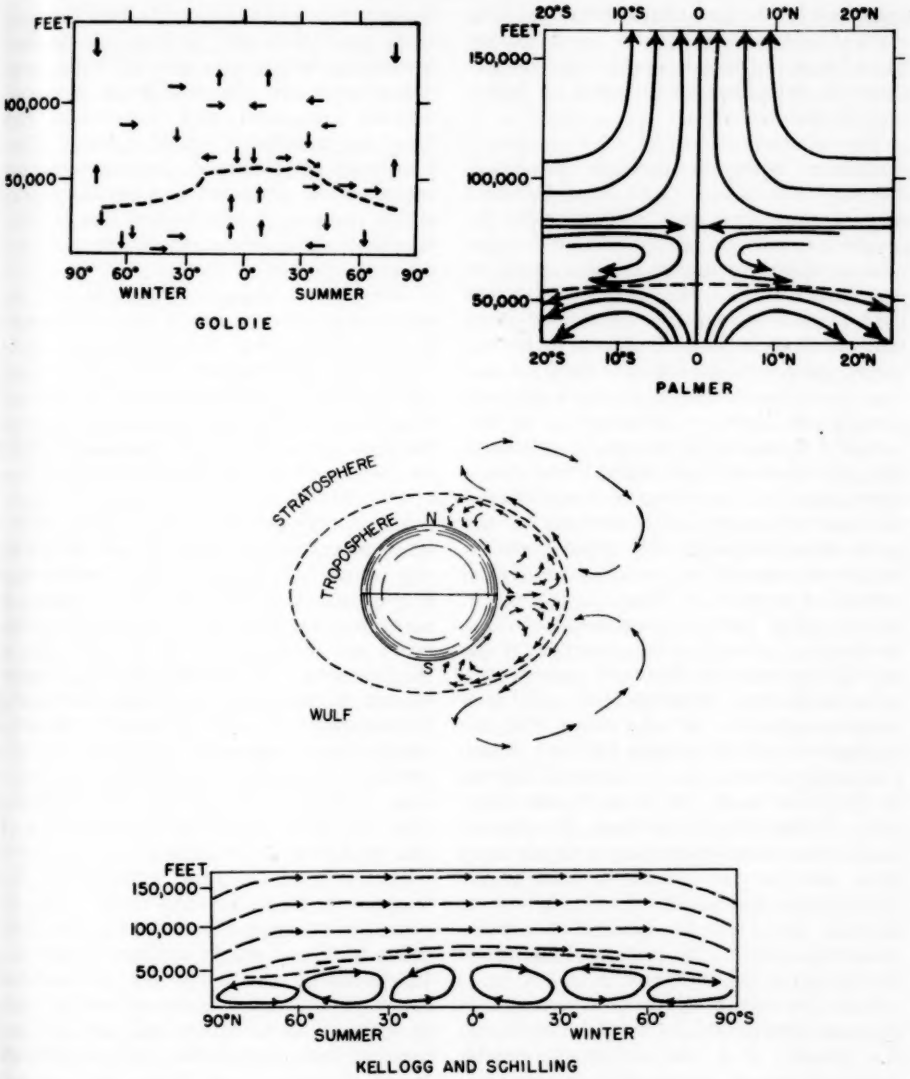

FIG. 6.

layed fallout. It is seen that the height of the bottom of the stratosphere, the tropopause, varies with latitude. It shows daily and seasonal variations in altitude at the same place.

The stratosphere differs from the troposphere in two important aspects. First and foremost, whereas the temperature decreases on the average of 6.5° C. per kilometer in the troposphere, there is either no temperature change with height or even, as in the tropics, an increase of temperature with height in the stratosphere. Second, the stratosphere is practically cloudless. The first difference means that there is very little vertical turbulence in the stratosphere

compared with the troposphere, so that vertical turbulent mixing is much slower. The absence of clouds means that the removal of debris cannot be aided by falling precipitation elements.

The absence of mixing in the vertical coordinate does not preclude horizontal diffusion, and, in fact, Parr's principle would suggest that horizontal mixing might be greater on account of the lack of vertical mixing. However, except for the spread of dust from Krakatao, the volcanic eruption of 1883, there is little or no evidence for either fast or slow horizontal mixing. Unfortunately, the optical detection of the Krakatao dust is not quantitative in the sense that it is possible to assign concentrations to the spread of the dust. There is reason to believe that the equatorial ring of the lower stratosphere may prevent exchange of air between the hemispheres just as is the case for the lower troposphere. In the troposphere, it is the convergence of air into the Intertropical Convergence Zone, as shown in Fig. 5, which prevents exchange. In the lower stratosphere, it is the steadiness of the east to west wind which would suggest little or no north-south exchange. This point is of some consequence. It may mean that the hemisphere with the atomic tests can obtain a disproportionate share of delayed fallout. On the other hand, the measurement of delayed fallout in the southern hemisphere means that some stratospheric debris must have entered the southern hemisphere. Conceivably, the path of the debris may be through the northern hemisphere tropopause and then to the southern hemisphere via the upper troposphere.

Since the vertical diffusion is very slow in the stratosphere and the north-south mixing also possibly slow, the meridional circulations may become important instruments for the transfer of the debris. In the next figure (6) are four published models of meridional circulations in the lower stratosphere. The models of Wulf, Goldie, and the lower part of Palmer display a cell which calls for sinking motion in the equatorial area, rising motion over the poles and appropriate north-south motions to complete the cells. The Palmer model suggests that above 80,000 feet in the Tropics, there is a reversal to rising motion. Kellogg and Schilling indicate that the main north-south drift will be from the summer toward the winter hemisphere. It should be remembered that the magnitude of the air motions associated with arrows on this figure are exceedingly small compared to the west-east air motions; centimeters per second or less compared to meters or tens of meters per second. It is evident that transfer processes within the stratosphere have not yet been resolved.

There is nothing unique about the problem of mixing across the tropopause. It is probable that the tropopause is the separation between fast and slow vertical mixing, but in itself represents no unusual barrier. In addition to air exchange through the tropopause, there are other possibilities for escape from the stratosphere. As was evident from many of the figures, the tropopause is believed to have a break in the temporate latitudes and the air exchange may occur here without any crossing of a tropopause. Secondly, in the course of everyday weather the tropopause disappears and reforms at different altitudes so that exchange of tropospheric and stratospheric can take place again without crossing the tropopause. Finally, in the polar areas the tropopause is often very indistinct and this combined with the expected sinking motion over cold sources suggests the possibility that the polar areas may be a region of transport from stratosphere to troposphere.

In theory, it is possible to predict the removal of the radioactive debris from the stratosphere given these non-weather data: the particle size, shape, and specific gravities to determine the extent of gravitational settling and the distribution of radioactivity in space. In practice, not only are the non-weather data unavailable, but the meteorological ingredients to effect the transport are not sufficiently well known.

Dr. W. F. Libby has presented an analysis which permits one to bypass all of these problems. He does not specify anything but the total amount of radioactivity available for delayed fallout and the amount which has been deposited during these first few years of the thermonuclear age. Libby computes the fraction of the stratospheric burden deposited each year, finds it to be

roughly 10 percent per year, and assumes that this fraction can be extrapolated into the future. This assumption yields an exponential decrease in the amount removed each year.

Libby's approach is very appealing in that it is now possible to obtain an answer to the first question: How fast is the radioactive debris being removed from the stratosphere? At the moment, there is no alternative to Libby's analysis, although one may argue for changes in details.

Two elements enter into the calculation of 10 percent removal per year. These are: the quantity in the stratosphere at the beginning of a given time interval and the amount removed from the atmosphere during the interval. Criticism will be limited to estimates of the annual deposition from delayed fallout.

The question of the removal of radioactive debris and, in particular, strontium-90, from the atmosphere is important to answer not only for the problem of stratospheric storage time but also for assessing the present strontium-90 level on earth.

All groups studying strontium-90 fallout, the most important part of delayed fallout, agree on two points: first, that most of it comes down in precipitation and second, that the strontium-90 is probably soluble in water. The Canadians and British state that about 85 percent comes down in rain. Libby has pointed out that Antofagasta in Chile, a location with essentially no precipitation, has a lower strontium-90 soil content by a factor of perhaps 50 than any other place on earth that has been sampled.

To understand how one computes the total strontium-90 deposition per year, it is necessary to review the sampling devices, especially in the light of the importance of precipitation. First, is the soil itself. Use of the soil as a method of integrating the worldwide delayed fallout has the following shortcomings:

1. The soil contains fallout from all times; it is a cumulative rather than a differential sampling device. However, successive sampling from the same locale may overcome this difficulty.

2. The leeching of strontium-90 is assumed to be small. The upper several inches are supposed to contain all that has fallen out.

3. There are water losses due to runoff during moderate and heavy rains or melting of snow packs.

4. Removal by impaction on vertical surfaces is not included except by plowing under of crops.

5. Sampling over the oceans and other water bodies is impossible. This is serious only if spray, wave action or some other ocean phenomena causes a systematic bias of the results compared with land.

6. Radiochemical analysis is difficult so that only limited numbers of geographical areas have been sampled.

The second most reliable technique is collection of precipitation samples by an open pot or funnel. These devices collect dry fallout as well as raindrops. It is evident that the pot or funnel is a differential sampler, suffers no leeching or runoff losses, could be used over oceans, and the radiochemical analysis is simpler than for soil. On the other hand, it is of uncertain efficiency for dry fallout and still provides no measure of interception on vertical surfaces. In the past, unfortunately, there has been a lack of observing points. Until recently, routine analysis of strontium-90 rainwater samples has been limited to one or two places.

On the other hand, there has been an extensive gummed film network. But the gummed film also suffers from a series of shortcomings.

1. With the small lip surrounding the film, the water running off the paper may be considerable. In fact, in a study by the Armour Research Foundation, the paper was found to be only about 10 percent efficient for a rainfall of 0.1 inch in one hour, for soluble substances.

2. During dry weather, the gummed film was found to develop an electrostatic charge at relative humidites below 45 percent. The result was a difference in collection efficiency by a factor of 6 between high and low humidities.

It is evident that the gummed film also may not have many of the difficulties assigned to the soil samples. At the few places where comparisons were possible, the gummed film does produce numbers which

appear to be consistent with the pot method, using an over-all collection efficiency of about 40 percent for strontium-90.

It has been the purpose of this review of collection methods to enumerate the likely sources of error in determining the total amount of fallout strontium-90 per year. It is evident that large random errors are likely and that there are errors whose magnitude and sign cannot even be estimated. But of these uncertainties whose sense can be determined, it is the present view that Libby's original estimate of 10 percent is too low. For example, Libby assumes no impaction on vertical surfaces, no runoff or leeching losses for his soil samples, and a 70 percent rather than 40 percent efficiency for the gummed film. It is, therefore, concluded that more than 10 percent comes down per year. Dr. Libby's more recent talks reflect this possibility. It would be highly desirable to ascertain whether the calculated removal of 10 percent per year very seriously underestimates the true deposition, since long residence in the stratosphere permits harmless decay and increases the likelihood of diffusive dilution.

Aside from the question of the actual deposition during the years following thermonuclear tests, there are also problems concerning the propriety of extrapolating the fractional removal of the stratospheric debris into the future. It is implied that the removal process is by diffusion and that the initial distribution is not such that the first year or two would yield anomolous results. With time, it will become evident whether the 10 per cent is constant. Already, however, there are data suggesting irregularities in the stratospheric removal. During 1955, according to the New York Operations Office, a large fraction of the strontium-90 fallout occurred in only 3 or 4 months in New York City rather than being spread evenly over the year. Lest one conclude that this is a seasonal affair, it may be noted that it did not take place in the same months of 1954 or in 1956.

It is concluded that Libby's approach to the determination of the rate of removal

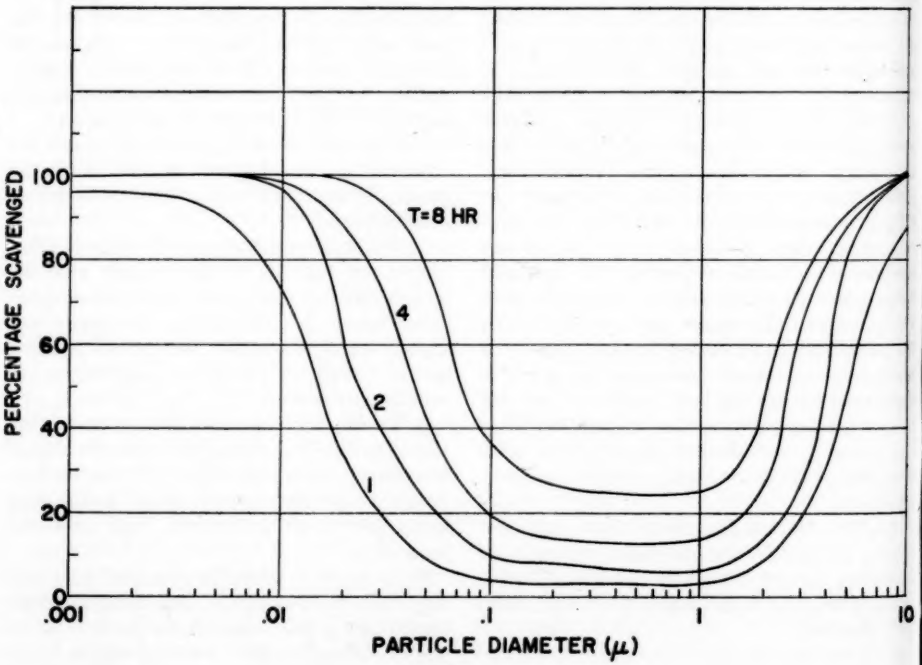

FIG. 7.

from the stratosphere is the best available but that it would be no surprise to find the percentage stratospheric removal to be far greater than 10 percent and to vary from year to year.

RAINFALL

Before concluding it may be worthwhile to evaluate more carefully how rainfall removes the delayed strontium-90 from the atmosphere in view of the fact that it is attached to such small particles. For particles whose diameters exceed a few microns, it has been demonstrated that inertia and interception by falling rain are reasonably efficient scrubbing agents but that for particles less than micron, this type of collection has an efficiency of zero. Stanley Greenfield of the Rand Corporation has analyzed another mechanism of precipitation scavenging of submicron particles. This is an agglomeration process whereby the agitation of the small particle results in a probability of impact on the water element. The scavenging efficiency is shown in the final figure (7) as the ordinate with the particle size as the abscissa. It is seen that to the right, with large particles, the efficiency is high as is the case for particles smaller than 0.1 micron, although for different reasons. In between, there is a "window" in which the removal by rain may be expected to be low. It is presumed that the delayed fallout is associated with particles below 0.1 micron, and therefore readily scavenged.

The delayed fallout, according to this hypothesis, should be removed by rain from the atmosphere largely at the level of the water cloud since the falling raindrop may not have enough time to allow agglomeration. However, actual comparison between strontium-90 content of rain and in the air suggests that a very thick layer of air must have had its particles scavenged. This suggests that by a mechanism, still not understood, even the falling droplet is capable of scavenging the particles of delayed fallout.

To this, one may add yet another bit of evidence which fails to fit into a simple picture. Although Antofagasta with its dry weather apparently contains practically no strontium-90, the correlation between rainfall and strontium-90 fallout is poor either when one considers the total amount of rain or the number of days with rain. Thus, Paris, a wet place, shows only half as much strontium-90 in the soil as does Damascus, Syria, a dry region.

It is hoped that further research on rainfall in relation to strontium-90 content will explain the numerous discrepancies that appear to be present.

CONCLUSION

Although, in principle, it is possible to plan a procedure for predicting the removal rate of delayed fallout from the stratosphere, in practice it is necessary to rely on the limited observations available to make the most reasonable estimate. It is recognized, however, that because the actual details are being omitted, the chance that serious errors are present becomes greater.

It is felt that stratospheric sampling holds a key to a more rational interpretation of the storage time. The distribution in time and space in the stratosphere may allow the meteorologist, with even his meagre information, to predict the desired quantities more reliably than at present.

As a final word, it might be added that the meteorologist stands to share in the knowledge which will be collected in the solution of the strontium-90 fallout problem.

When a fact appears to be opposed to a whole train of deductions, it invariably proves to be capable of bearing some other interpretation.—SHERLOCK HOLMES.

PHYSICS.—*Global distribution of radioactivity from nuclear detonations, with special reference to strontium*[90].[1]

MERRIL EISENBUD, New York Operations Office, Atomic Energy Commission. (Communicated by Chester H. Page.)

The properties that make strontium[90] the most hazardous of the nuclides formed in the fission process are its long half-life (28 years) and its chemical similarity to calcium. Because of its resemblance to calcium, Sr^{90} may be assimilated by biological processes. If ingested by humans in food or water, the strontium will deposit, like calcium, in the skeleton.

Investigation of the potential hazard from contamination of soils and the biological food chains by Sr^{90} began very early in the United States atomic-energy program. The first studies, associated with the wartime weapons development program, were theoretical and were designed to identify the principal parameters which influence the long range effects of nuclear detonations. It was clear from the start that studies of radioactive fallout, and of the ultimate fate of Sr^{90} in particular, would require the application of knowledge from a wide assortment of the physical and biological sciences. The initial theoretical studies provided a valuable basis for the experimental approach to the problem which became possible with the programs of weapons testing which began in 1948 and have continued intermittently to the present time.

The Sr^{90} studies have increased in scope and complexity, and the over-all program has for some years been global in extent, involving physical, chemical, and biological investigations on land, in the oceans and in the air. Known as Project Sunshine, and directed at a full understanding of the physical and biological behavior of the Sr^{90} produced in nuclear detonations, these studies are concerned with an unprecedented variety of scientific questions. From the standpoint of its vast geographical dimensions and the variety of scientific mechanisms involved in the investigation, Project Sunshine rivals the most comprehensive scientific studies ever undertaken.

[1] Presented at the Washington Academy of Sciences Fall Symposium, Washington, D. C., on November 15, 1956.

The factors that influence the behavior of Sr^{90} begin in the complex physics and chemistry of the fireball and the mushroom shaped cloud which forms after a nuclear detonation. The height of the burst above ground, the nature of the terrain and the particle size of the soil and debris sucked into the fireball, all influence the fallout pattern.

When the particles descend to the earth's surface, they leave the domain of the meteorologist and become involved in the physics, chemistry and biology of the soil. How soluble is the Sr^{90} in fallout? Does it leach from the soil? At what rate is it incorporated into plants and how can this rate be expressed quantitatively as a function of type of soil and type of plant? These are a few of the questions that have been studied in tracing the Sr^{90} into the first of the biological links in the food chain between soil and man. The answers to these and many more questions have been obtained by many investigators working in many laboratories throughout the country.

From its formation in a nuclear detonation, until it is metabolized by man, the path of a Sr^{90} atom is long and tortuous. Understanding of its route has come from studies which know none of the bounds of any one of the conventional scientific disciplines. The phenomenology of Sr^{90} in fallout can only be described in the combined languages of all the principal combined sciences, geophysics, physical chemistry, biophysics, and biological chemistry.

In this discussion an effort will be made to present the state of knowledge in such a way as to emphasize only those portions of the overall Project Sunshine studies that are concerned directly with an estimation of the human hazard from Sr^{90}. In so doing, many interesting and important scientific questions will be deliberately by-passed. Where a pertinent question cannot be answered because of insufficient knowledge, the most conservative possible assumptions will be made thereby tending to yield results which define the upper limit of the potential hazard.

Libby (1) (2), has recently reported on the many ramifications of Project Sunshine. He has called attention to the physical and biological concepts which serve as the basis for the approach taken in the Sunshine studies and has presented a thorough evaluation of many of the data.

WORLDWIDE DEPOSITION OF FALLOUT

The basic procedure for documenting the global fallout of radioactivity is by means of a network of monitoring stations which have been operated in the United States and abroad since 1951. Until recently this network consisted of 88 stations located in 46 countries and territories. During the past few months the network has been augmented by a number of stations sponsored by various additional governments in cooperation with the U. S. Atomic Energy Commission. The data from this monitoring network have been periodically summarized (12) (13) (4).

The monitoring technique is a simple one which consists of exposing a one square foot cellulose ester film covered with an adhesive. The radioactivity in fallout is largely in particulate form and the dust is collected by impaction against the adhesive surface. The coating is insoluble and retains its adhesive properties when wet, so that in rain the radioactive dust particles are retained by the collection surface. These films are exposed in duplicate for 24 hours, after which the film is mailed to a central processing facility at the AEC Health and Safety Laboratory in New York. Most of the stations are located at meteorological observatories where the collection routine can be easily fitted into the schedule of observations and duties.

From 1951 until the latter part of 1955, the period covered by this report, it was a relatively simple matter to determine the age of the mixed fission products collected daily by the monitoring network. At any given time the fallout was known to have originated from the most recent test series. Prior to 1954, the fallout from the detonations would diminish rapidly and would ordinarily be undetectable before the next series of tests started. This was because the yields from detonations were relatively low, and the bulk of the debris was distributed below the tropopause, where fallout is greatly hastened by precipitation and other factors.

The ease with which the age of the radioactive debris could be determined made it a simple matter to estimate the fraction of the total radioactivity that was due to Sr^{90}, by using the curves of relative isotopic abundance of fission products developed by Hunter and Ballou (3).

The detonation of devices having yields equivalent to megatons of TNT produces clouds of radioactive debris which pierce the tropopause and become distributed in the stratosphere. From this relatively stable region of the earth's atmosphere, the particles descend slowly, and fallout to the earth's surface occurs over a period of time which is measured in years rather than weeks or months. The traces of relatively old debris from high-yield devices become mixed with the debris of subsequent detonations. This being the case, neither the decay characteristics of a sample nor the relative abundance of the long-lived isotopes can be predicted from theory.

Late in 1955, it became apparent that it was increasingly difficult to predict the Sr^{90} of fallout from theory, because of the mixing of debris from more than one test series. The method of estimating Sr^{90} was therefore changed. At the present time increasing reliance is placed on direct radiochemical analyses of the contents of pots which collect the fallout continuously for one month. The gummed films will continue to be used as the basic collection device because its simplicity makes it possible to obtain data from a great number of stations. Unfortunately films cannot be analyzed directly for Sr^{90}, and it has therefore been necessary to devise other means of determining the ratio of Sr^{90} to total fission product activity.

Calibration of these gummed films against cylindrical pots indicates that the technique has an efficiency of about 63 percent for collection of mixed fission products. The sacrifice in collection efficiency is justified by the ease with which the samples can be collected, transported and analyzed.

The pair of gummed films present a sam-

pling area of 2 square feet per station. Thus, the total area sampled by the network is 176 square feet which is only 3×10^{-14} of the area of the earth. One must therefore inquire as to the adequacy of the coverage provided by the sampling network and the possibility that areas of the world may exist in which the Sr^{90} deposition is very much higher than the values observed at sampling stations located hundreds of miles apart.

Table 1 provides a regional summary of the cumulative fallout of Sr^{90} reported for the collection stations. Stations in the immediate vicinity of the test sites in Nevada and the Marshall Islands are excluded because, as expected, the fallout patterns in these regions is less regular than elsewhere and the data are therefore not applicable to a discussion of global fallout phenomena.

TABLE 1.—REGIONAL SUMMARY OF Sr^{90} DEPOSITION AS OF SEPTEMBER 1, 1955

Place	No. Stations	Range mc/mi²	Mean mc/mi²
Europe and the Middle East	6	4.0–5.9	5.0
Africa	7	3.0–6.7	5.4
Japan and southeast Asia	11	4.5–11	7.0
Australia and New Zealand	4	3.3–5.6	4.8
Latin America	12	2.9–8.3	5.4
Canada and Alaska	13	3.0–6.9	5.1
United States	22	3.4–13	7.8

Table 1 reveals a high degree of uniformity in the cumulative deposition of Sr^{90}. The mean of the means of the seven geographical areas is 5.8 mc/mi² and the range of values for the 75 stations included in the table is 2.9–13 mc/mi². Only two stations in the United States (Boise and Memphis) and none of the overseas stations have values greater than twice the mean of the area means. The uniformity of the depositions suggest it is unlikely that Sr^{90} exists in any part of the world (excluding regions near testing sites) in amounts greatly in excess of the upper values reported in the table.

Previously, Libby (2) has called attention to a band of relatively high fallout in the Northern Hemisphere. This band, which Libby attributes to the relatively rapid fallout of trophospheric debris in the latitudes of the detonations, is not as marked in the worldwide pattern of the gummed film network, although the values for the United States, Japan, and southeast Asia are noted to be about 50 percent higher than elsewhere. In general, the values reported here for the Southern Hemisphere are higher than those reported by Libby, but the differences are of little significance in the ultimate estimates of the potential human hazard.

In October 1955, 17 samples of soils were collected in the United States at places where the adhesive films had been in use since 1951. This study, which has been previously reported (4) indicated that the measured values of strontium in soil were on the average of 1.6 times the estimates based on film collections. It was noted that this relationship did not hold for sampling locations situated near the Nevada test site and it was tentatively concluded that the relative enrichment of Sr^{90} in the soils at a distance from the test site was due to the fractionation of Sr^{90} in the early development of the radioactive cloud. Perhaps the reason is due instead to peculiarities of the desert soils of that region.

More recent analyses of soils at a number of overseas locations have not indicated a clear cut relationship between the estimates of fallout derived from soil analyses and from adhesive films. In Figure 1 are given the results of soil analyses from various parts of the world, as reported by the University of Chicago (5). The data are plotted against the estimated values of Sr^{90} based on predictions from the adhesive film network. In general the estimated values are somewhat higher than the measured values. The reason for this is not understood. The obvious possibility that the Sr^{90} is leaching from the soil seems unlikely in view of other data which indicate conclusively that the bulk of strontium^{90} in undisturbed soil is retained in the upper two inches and vertical leaching may therefore be said to be negligible. The possibility that the debris is washed horizontally cannot be disregarded although this possibility seems to be ruled out by other evidence that the debris tends to remain fixed at the site of

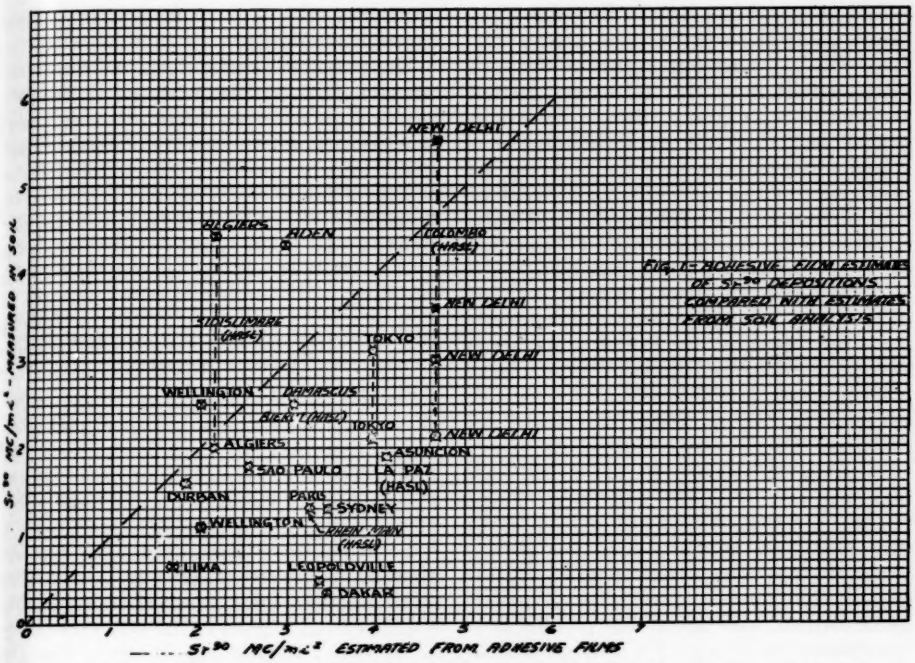

FIG. 1. Adhesive film estimates of Sr^{90} depositions compared with estimates from soil analysis

original deposition. The recovery of Sr^{90} from soils is an exceedingly difficult chemical procedure and it is possible that incomplete recovery of the isotope may in part explain the discrepancy noted.

Although the number of sampling locations are relatively few in relation to the total surface of the earth, and although no data are available for the large ocean masses, the uniformity of the cumulative deposition of Sr^{90} makes it possible to estimate the total Sr^{90} deposition over the surface of the earth. The integrated total, based on the adhesive film measurements, at the end of September 1955 is estimated to have been one million curies, with an average deposition of 5 mc/mi².

ESTIMATE OF STRATOSPHERIC RESERVE OF SR^{90}

A complicating factor in the Sr^{90} studies is that megaton devices inject substantial amounts of fission products into the stratosphere from which depletion occurs at a relatively slow rate. Evaluation of the potential hazard from the radiostrontium produced up to any given time requires that we consider not only the Sr^{90} already deposited on the earth's surface, but also that which remains in stratospheric storage and will be deposited at some future time.

Libby has postulated (1) that the stratospheric reservoir is depleted exponentially, with 50 percent being removed every 7 years. More recent data indicate that this estimate may be slightly high, but the true halftime of deposition is certainly greater than 4 years.

The stratospheric residence time of the bulk of the debris is certainly short in relation to the radiological half-life of Sr^{90}. If the debris were to be stored in the upper air for a period as long or longer than the half-life of Sr^{90} (28 years) the potential hazard would be significantly less because radioactive decay would eliminate appreciable amounts of Sr^{90} before deposition to the earth's surface takes place. However, since the mean residence time in the stratosphere can be taken to be much less than 28 years,

only a small fraction of the Sr^{90} will decay before being deposited on the earth's surface. One can therefore estimate the ultimate deposition of Sr^{90} by assuming that this nuclide is uniformly mixed in the stratosphere and that the total amount now stored in the stratosophere will be deposited uniformly on the earth's surface. Whether this deposition will be complete in 5 years or 10 is of minor importance in estimating the potential hazard to be expected.

It is possible to sample the stratospheric dust burden and a number of measurements have been reported by British and United States investigators (6). Both groups have collected samples of dust by filtering air, using aircraft up to about 45,000 feet. In addition, the United States has flown constant level balloons up to 100,000 feet, and has collected dust samples by electrostatic precipitation as well as by filtering air. The data obtained in these studies indicate that the stratospheric Sr^{90} is present in approximately the expected amounts but there are at the present time insufficient data to permit reliable estimation of the total stratospheric reservoir of Sr^{90}.

A better estimate of the stratospheric reserve can be obtained at present from material balance studies. The amount of Sr^{90} produced in detonations to date can be estimated with some certainty. Estimates of the amounts of Sr^{90} that are deposited in the intense fallout in the vicinity of a detonation are available from extensive investigations conducted during the test programs in Nevada and in the Pacific. The total strontium produced in a detonation, less the Sr^{90} which falls out in the immediate vicinity of the detonation, gives the total inventory of Sr^{90} that is available for subsequent deposition at places remote from the site of detonation.

Based on this approach, it is estimated that the present stratospheric inventory of Sr^{90} from detonations to the present time is about three times the total amount that has already been deposited outside of the United States. In the United States, Sr^{90} from the Nevada tests was a significant fraction of the Sr^{90} fallout at the end of 1955, so that the proportionate increase will be less in the future from the more uniform deposition of stratospheric debris.

The probable average level of worldwide contamination by Sr^{90}, when all of the Sr^{90} produced to date has been deposited, may be approximated as about 20 millicuries per square mile, by adding 15 mc/mi² to the average deposition of 5 mc/mi² at the end of 1955. This estimate, based on data from the adhesive film network is in good agreement with Libby's recent (2) estimate of 15–17 mc/mi².

THE HUMAN SIGNIFICANCE OF STRONTIUM LEVELS IN SOIL

The deposition of Sr^{90} in soil must be related to assimilation by biological processes and to absorption by man. The presence of this isotope in soil is significant only because it is potentially available for assimilation by plants, animals, and ultimately man.

To define the potential risk from a given distribution of Sr^{90} on the surface of the earth requires that the distribution be quantitatively related to the skeletal burden of Sr^{90} of a human population in dietary equilibrium with the soil from which their nourishment is derived. This equilibrium is already established for a variety of trace elements normally present in the earth's crust. Some of these, like potassium and radium are radioactive and this is reflected by the presence of these substances in the human body. For example, the upper foot of soil in the United States contains, on the average, about 1,000 millicuries of radium per square mile. The average adult skeleton in this country contains about 10^{-4} μc of radium which is derived from assimilation of this trace element from foods and water. Thus, the value of 10^{-4} μc of radium represents the amount deposited in the skeletons of the populations whose mineral metabolism is in equilibrium with the soil minerals.

The freshly deposited Sr^{90} takes a relatively long time to complete the biological route to bone. At the present time the skeletons of all but very young children were formed prior to the introduction of Sr^{90} to the soil. Moreover, bone being formed at the present time utilizes calcium which left the soil in months gone by. The fact that cattle may be fed on hay many months old and the

hold-up of human foods in the commercial distribution system, are but two of many factors which would lead one to expect the human Sr^{90} burden to lag in time behind the potential value which might ultimately be expected from a given soil concentration. The human skeleton cannot be expected to respond quickly to the gradual accretion of Sr^{90} by soil. Equilibrium can be expected to be achieved over a period of years but not over a period of months.

In the United States as in a number of other parts of the world where the population derives much of its calcium from dairy products, analyses of milk for Sr^{90} provides a method of estimating the levels of human absorption which may be expected in the future.

Recent studies by Comar (9) have shown that when radiostrontium is incorporated into milk there is no appreciable biological differentiation between calcium and strontium when the milk is fed either to experimental animals or to humans. One may therefore assume that when a skeleton is formed by calcium from dairy products, the skeleton will contain the same Sr^{90}-Ca ratio that was present in the food. This is apt to be a conservative assumption, other investigations having demonstrated that biological differentiation may take place whereby the specific activity of the calcium in the diet may be as much as $2\frac{1}{2}$ times greater than the specific activity of the calcium deposited in the skeleton. If the assumption that no differentiation takes place is not valid, the error will be on the safe side since all of the experimental evidence indicates that when differential absorption does occur it is in favor of calcium.

Milk from the metropolitan New York milkshed has been sampled regularly since early 1954. In 1955 the sampling program was expanded to include other milksheds in the United States and abroad. The Sr^{90} content of the New York milk is presented graphically in Fig. 2 and Table 2 gives the average value for all sampling locations during the first half of 1956.

As Sr^{90} is not a natural constituent of the earth's crust, it follows that the presence of this isotope in biological materials is due to fallout from the detonation of nuclear

TABLE 2.—Sr^{90} IN MILK—JAN.-JUNE 1956
(All values in $\mu\mu c$ Sr^{90}/gm Ca)

Month	N. Y.	State College, Miss.	Madison, Wis.	Mandan, N. Dak.	Portland, Oreg.	Japan	England
Jan.	2.3	—	3.0	3.5	—	2.7	4.0
Feb.	2.0	—	3.5	8.1	—	—	4.6
March	2.0	6.3	3.4	11.	—	3.5	4.0
April	2.9	6.7	3.4	7.7	5.2	3.0	—
May	2.8	4.9	2.8	10.	6.4	—	2.9
June	3.0	4.4	3.4	8.7	5.0	—	—
Average	2.5	5.6	3.3	8.2	5.5	3.1	3.9

devices during the past few years. Insufficient time has elapsed to reveal whether or not the concentration of Sr^{90} in milk bears a linear relationship to the accumulating Sr^{90} in soil. The value of between 2 and 3 micromicrocuries Sr^{90}/gram of calcium, representing the average range of values reported from mid-1955 to mid-1956, can be explained in two ways, both of which involve contamination of the cattle feed. This contamination may occur by way of the soil, in which case the Sr^{90} is incorporated metabolically into the feed, or the contamination may exist as freshly deposited fission products on the surface of the plant.

If the contamination in milk results primarily from the latter factor, it would be expected that a cessation of nuclear detonations would be reflected by a diminution of the Sr^{90} content in the coming years as the stratospheric inventory of Sr^{90} becomes depleted and the fallout onto the surfaces of the feed becomes correspondingly less. On the other hand, if the contamination of milk is due primarily to the Sr^{90} incorporated metabolically from the soil, the concentration in milk would be expected to increase in proportion to the Sr^{90} in soil. The maximum concentration in milk would be reached after the stratospheric reservoir has been deposited in the soils.

It will be noted from Fig. 2 that a steep rise occurred in the metropolitan New York milk supply in early September 1956. It is not now known whether this rise is due to the relatively heavy fresh fall-out from foreign detonations conducted last summer or to an increase in the amount of Sr^{90} incorporated metabolically from the increasing amounts

of Sr^{90} in the soil. If the former hypothesis is valid, the milk concentration can be expected to diminish in succeeding weeks. If the increase is sustained, it is presumably a reflection of the increasing amount of Sr^{90} in soil. As a basis for comparison with the soil values, the curve of cumulative Sr^{90} in the New York area is superimposed on the milk curve. It will be noted that since 1954 the cumulative fallout of Sr^{90} is increasing steadily with time, but even if one accepts the recent increase in the Sr^{90} content of milk, the latter is at a much slower rate.

The deposition of Sr^{90} in the soils of the metropolitan New York milkshed in the early fall of 1955 is estimated to have been 6.5 mc/mi². The expected maximum in this area is thus 21.5 mc/mi² when the stratospheric inventory of Sr^{90} is deposited. This is an increase by a factor of 3.3. In the summer of 1955 the milk in this area averaged 2.5 $\mu\mu$c/gm Calcium. If we assume that the milk concentrations will increase in proportion to the soil content of Sr^{90}, the maximum value that can be attained in metropolitan New York milk of the future, from detonations to date, is about 8.3 $\mu\mu$c Sr^{90}/gm Calcium. It should be again noted that this is a conservative assumption which ignores the possibility that much of the Sr^{90} in milk may be ingested by the cows as fresh fallout on the surface of plants. If we further assume that no differentiation between strontium and calcium will occur in the process of converting milk to human bone, 8 $\mu\mu$c Sr^{90}/gm of skeletal calcium becomes the upper limit of the foreseeable strontium burden in the population of this area from detonations which have already occurred. A factor of 3 should be ample to define the upper limit of hazard elsewhere in the United States where, as in North Dakota, the Sr^{90} uptake is proportionately higher than in metropolitan New York. On this basis, 25 $\mu\mu$c Sr^{90}/gm Calcium is the highest foreseeable skeletal burden in the United States. This estimate is likely to be reduced as new information about the uptake of Sr^{90} eliminates some of the uncertainties which have prompted the use of highly conservative assumptions. Although this estimate is higher than Libby's recently estimated upper value of 10 $\mu\mu$c/gm Ca, the agreement is excellent considering

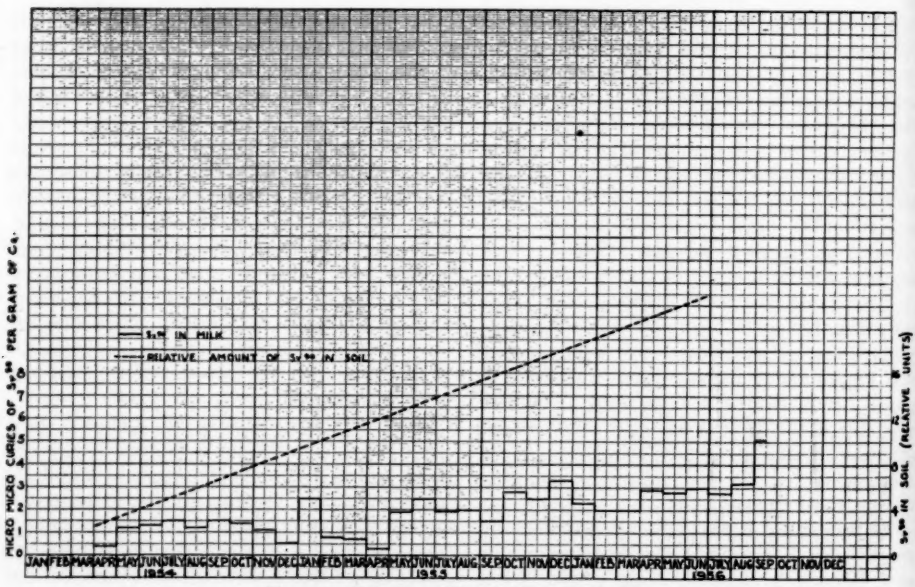
Sr90 IN MILK
RELATIVE AMOUNT OF Sr90 IN SOIL
MICRO MICRO CURIES OF Sr90 PER GRAM OF Ca.
Sr90 IN SOIL (RELATIVE UNITS)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1954
1955
1956

FIG. 2.—Sr^{90} in milk of New York, N. Y.

the fact that the two estimates are based on different approaches and that both are deliberately conservative.

The data from the worldwide fallout collection network indicate that the fallout is distributed throughout the portion of the world that has been sampled in a remarkably uniform manner. If the potential strontium hazard in an agricultural area anywhere is greater than in those areas in the United States for which the milk data in Table 2 serve as indices, the reason is likely to be found in the soil chemistry of the region or the dietary habits of the people.

There is good evidence that the uptake of Sr^{90} is markedly influenced by the amount of calcium available to growing plants. For any given amount of Sr^{90} in soil, the uptake into plants will vary inversely with the available calcium present in the soil. Plants growing on soils which are depleted in calcium assimilate more Sr^{90} than otherwise.

The manner in which differences in the dietary habits of populations influence the Sr^{90} uptake requires further study. Leafy vegetables can be expected to have a higher ratio of Sr^{90} to calcium because of direct deposition on the surface of the leaves. For example, in a crop of snapbeans grown in Maryland in the summer of 1956, the leaves assayed 78 $\mu\mu c$ Sr^{90}/gm Ca whereas the beans assayed only 2.2 $\mu\mu c$ Sr^{90}/gm Ca. As it is doubtful that any differentiation between strontium and calcium occurs metabolically within the plant, the difference is presumed to be due to the distribution of fresh fallout on the leaves.

Two methods are available for quickly screening populations to determine if any unusual factor or combination of factors is contributing to a higher Sr^{90} uptake. Although the sampling of human bones is of limited value in assessing the Sr^{90} burden which may be expected when an equilibrium is reached, the method is satisfactory for comparing populations at any given time. Kulp and Eckelmann (10) have recently completed several hundred analyses of human bones from various countries of the world and find little difference between one area and another except that United States values, on the average, are higher than those which they found elsewhere in the world. They report an average of 0.35 micromicrocuries Sr^{90} per gram of calcium in bones of Eastern United States' children at a time when the milk assayed almost 10 times as high.

Another screening method which appears promising is the analysis of pooled urine samples. Only a few data are available but it is known that Sr^{90} is detectable in the urine of individuals in Eastern United States. The level in early summer of 1956 was about 1 to 2 disintegrations per minute per liter. In a population in which the dietary intake of Sr^{90} is relatively uniform, the Sr^{90} excretion can perhaps be used as a measure of the Sr^{90} intake. Additional data should be obtained for other parts of the United States and for other countries as well.

THE HAZARD OF STRONTIUM^{90} IN BONE

The above reasoning suggests that a maximum of 25 micromicrocuries of Sr^{90} per gram of calcium is foreseeable in human bones perhaps a decade hence when biological equilibrium is reached with the Sr^{90} produced up to the present time. This figure is arrived at by making the deliberately conservative assumption that the presently observed values of Sr^{90} in milk represent the equilibrium values between milk and soil, and that henceforth the milk concentration of Sr^{90} will bear a linear relationship to the deposition of Sr^{90} in soil. It is further assumed that the human body does not differentiate between strontium and calcium and that the specific activity of skeletal calcium will therefore be equal to the specific activity of milk calcium. The value of 25 $\mu\mu c$ Sr^{90}/gm Ca may overestimate the true value by a factor of 10. 25 $\mu\mu c$ Sr^{90}/gm Ca, allowing for simultaneous decay of the isotope in both the soil and bone, will deliver a dose of 2.3 rep to the skeleton over a lifetime of 70 years. This compares to a normal range of skeletal irradiation of 7 to 30 reps due to K^{40}, C^{14}, cosmic rays, terrestrial gamma radiation, and natural radium. The maximum foreseeable value of 25 $\mu\mu c$ Sr^{90}/gm Ca when integrated over the life span, is thus equiv-

alent to 7.6 to 33 percent of the dose from natural sources of skeletal radiation.

The variability of the skeletal dose due to natural radioactivity is largely due to differences in the body radium content, which has been shown to vary from one geographical region to another. For example, it is reported (11) that in Illinois the skeletal dose from radium alone varies between 6.7 and 67 millireps per year (0.47 to 4.7 reps in 70 years). The gamma ray dose received externally from terrestrial sources is likewise quite variable depending on the kinds of rocks in the vicinity.

If we take 30 reps in 70 years as the upper limit of skeletal irradiation from natural radioactivity in the United States, the skeletal burden from Sr^{90} from detonations to date could reach peak values as high as 330 micromicrocuries per gram of calcium before the maximum skeletal dose from *natural* radioactivity would be doubled.

The National Committee on Radiation Protection recommends one microcurie of Sr^{90} as the maximum permissible continuous burden for occupational exposure. It is generally accepted that for public exposure an additional safety factor of 10 is advisable, and on this basis 1/10 of a microcurie of Sr^{90} would be the maximum permissible body burden for public exposure. This is equivalent to 100 micromicrocuries of Sr^{90} per gram of skeletal calcium. The conservatism of this value is illustrated by the fact that the dose delivered to the skeleton by a constant deposit of 100 micromicrocuries Sr^{90} per gram of calcium is 20 reps in 70 years which is somewhat less than the upper limit of dose delivered by natural sources alone. The recommended maximum value of 100 $\mu\mu$c/gm Ca, being intended for continuous exposure is not directly applicable to an evaluation of the potential risk from detonations to date. The natural radioactive decay of Sr^{90} will reduce to about 0.5 the dose delivered in the lifetime of individuals who, from birth, begin to accumulate skeletal calcium initially containing 25 $\mu\mu$c/gm.

SUMMARY

The worldwide distribution of the Sr^{90} produced in weapons tests up to the present time can be expected to rise to approximately 20 millicuries per square mile in the latter part of the next decade. Because of the chemical resemblance of strontium to calcium, Sr^{90} tends to be assimilated by plants, ultimately finding its way into foods and man, where the maximum foreseeable deposition in humans will produce a radiation dose to the skeleton that will be about 2.3 reps in a lifetime of 70 years. This estimate is based on conservative assumptions, and in all probability the actual dose will be considerably less, possibly as low as 0.23 rep. The dose in the United States from natural radioactivity, to which humans have always been exposed, ranges from 7 to 30 reps in 70 years. The highest estimate of the skeletal dose that can be foreseen from devices detonated to date is thus 7 percent of the upper values of the dose delivered by natural radioactivity and may prove to be as little as 0.7 percent.

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PHYSICS.—*Immediate radiations from a nuclear detonation.*[1] GORDON DUNNING, United States Atomic Energy Commission. (Communicated by Chester H. Page.)

I. THE FIREBALL AND THERMAL RADIATION

At the time of a nuclear detonation the temperature inside the fireball rises to several million degrees. The temperature decreases markedly within a small fraction of a second, yet even some of the relatively small devices fired at the Nevada Test Site have produced sufficient light to be seen over 400 miles away. About one-third of the total energy of an air burst is represented by this thermal radiation.

The size of the fireball created by the nuclear detonation depends upon the yield (energy) of the burst; indeed, it is a good index of magnitude of the detonation. A 20-kiloton burst (20,000 tons TNT equivalent) will create a fireball of about 600 feet in radius. This value may be scaled to other size detonations by the relationship

$$\frac{R}{RO} = \left(\frac{W}{WO}\right)^{2/5}$$

Where: RO = maximum radius of reference burst
WO = yield of reference burst
R = maximum radius of new burst
W = yield of new burst

For example, a 10-megaton burst probably would produce a fireball over 7,000 feet in radius, or more than 2½ miles across.

The surface of the fireball exhibits characteristic two temperature pulses after a detonation. The initial temperature of 10,000° (K) or so will drop to about 2,000° (K), rise again to perhaps 8,000° (K) and then drop off continuously with time. The time between these events becomes greater with increasing yields of bursts. The explanation is somewhat complex but a simplified description follows. The nuclear detonation creates pressures in the order of millions of pounds per square inch. The resultant shock front originally coincides with the surface of the fireball, but for the time that the temperature drops during the first pulse, the shock front advances more rapidly than the fireball surface, creating a zone of cooler air. The visible (and infrared) radiations travel outward from the fireball through this zone with the velocity of light and with a relatively small attenuation. However, owing to the high initial temperature of the fireball about 70 percent of the radiations in the first pulse is in the ultraviolet region. This radiation is strongly absorbed by the nitrogen or oxygen ions, converting them into an excited state, from which they quickly revert to a lower level by re-emission. However, these re-emissions are in random directions so that although the radiation is traveling with the speed of light, the forward speed is relatively small. As the fireball continues to expand and cool the proportion of the thermal energy appearing in the longer wave length region at the surface of the fireball increases. These are much less attenuated than the ultraviolet radiations, accounting for the rise in apparent luminosity. The luminosity eventually drops off, of course, owing to the continued expanding and cooling.

Only about 1 percent of the total thermal energy appears in the first pulse. This, together with the fact that most of this energy is in the ultraviolet region which is highly attenuated, means that the first pulse contributes in only a minor degree to the production of burns.

Perhaps surprisingly, the temperatures of the fireball surfaces are not greatly different for various yields of bursts, but the durations of the temperature pulses are a function of the size of the detonation. The time to the peak of the second maximum is proportional to the square root of the yield of the burst. Thus for a 20-kiloton detonation this time is about 0.14 second, while for a 10-megaton burst the time will be about 3.2 seconds. The degree of burns produced depends not only upon the total energy per unit area received but also somewhat upon the duration

[1] Presented at the Washington Academy of Sciences Fall Symposium, Washington, D. C., November 15, 1956.

of delivery of this energy, i.e., the longer the delivery time the greater the total energy required to produce a burn. This may not be a major effect, however, since the increase in total energy required to produce a given degree of burn is less than a factor of 2, between a 1 kiloton versus a 10-megaton burst. (A factor of 10,000 difference in yield.) There is another consequence, however, of the rate of delivery of the thermal energy that may be of much greater importance. The rate of delivery for a given total thermal energy is relatively fast for lower yield bursts, but it is appreciably slower for higher yield detonations, thus suggesting the possibility of effective evasive action for the larger bursts.

The total thermal energy reaching a given point is a function of (a) yield, (b) distance from burst, and (c) state of the atmosphere. The effect of varying yields has been discussed except for one factor. For a given size burst, the thermal effects of a surface shot will be significantly less than for an air burst, i.e., the distances from the burst to the point where skin burns are produced may be less by some 40 percent. This is because a portion of the thermal energy is absorbed by the earth and also the thermal radiation reaching a target will have to travel through the air near the earth's surface which produces a greater attenuation.

If attenuation is neglected, the energy received per unit area drops off as the square of the distance. For example, the energy per unit area at 4 miles is one-fourth that at 2 miles.

The influence of the state of the atmosphere is more complex. Different wavelengths will be scattered by different amounts owing to the presence of particles in the air. However, a generalized estimate may be made in terms of "visibility," which is defined as the horizontal distance at which a large dark object can be seen against the sky in day-light. For example, on a very clear day the visibility may be about 15–30 miles and for a day with a light haze about 3–6 miles. It might first appear that the amount of thermal energy received at a distance would be strongly a function of the degree of visibility. However, it is now thought that for distances that are about one-half or less of any given visibility range (except for very hazy days), that the amount of thermal radiation received does not depend greatly on the visibility. This may be explained as follows: For a clear day most of the thermal radiation received is that directly transmitted with little contribution from the scatter radiation. For conditions where moderate numbers of particles are present in the air, the loss in direct transmission is largely compensated by the increased scattered radiation. Of course, dense fog or smoke can very materially decrease the intensity of the thermal radiation—perhaps by a factor as great as 10.

The thermal radiation falling on a target may be in part absorbed, reflected, or transmitted. Dark material will, of course, absorb more of the thermal radiation, but if a substance chars in the early stages of the exposure, it too may become a good absorber. In the case of clothing this absorbed heat may be transferred to the skin and produce contact burns. Any opaque object will eliminate the direct thermal radiation and thus produce the shadow effect that was obvious in many instances in Japan, both for effects on materials and on the production of the so-called "flash burns" on the skin.

Since the transmission of heat by conduction through the skin is relatively slow the absorbed energy is principally confined to shallow depths of the skin. The type of burn thus produced does not differ significantly from the more usual kind, in terms of treatment or general bodily effects. For example, they are categorized in the same three general classes of first, second, and third degree burns. They may represent a major contributory factor to casualties in the event of an atomic attack. For example, in the Japanese bombing it has been estimated that 20 to 30 percent of the fatal casualties were due to flash burns.

The above discussion indicates the difficulty in making generalized estimates of the severity of burns from different yield detonations under varying conditions. However, Table 1 represents one set of estimates based on the assumptions of an air burst on a clear day.

TABLE 1.—APPROXIMATE DISTANCES (MILES) FROM AN AIR BURST ON A CLEAR DAY TO PRODUCE THE DEGREES OF SKIN BURNS SHOWN

Yield (kilotons)	Degree Burns		
	1st	2d	3d
20	2.4	1.6	1.4
200	6.4	4.4	3.8
1,000	12	9	8
5,000	25	18	15
20,000	44	32	28

II. NUCLEAR RADIATIONS

The nuclear radiations of principal interest at the time of a detonation are gamma rays and neutrons. Most of the gamma rays resulting from the actual fission process are absorbed by the bomb materials. However, there are three other processes that result in the production of other gamma rays.

One, a large portion of the neutrons are captured by nonfissionable nuclei, converting them to a high energy state. Almost at once these nuclei revert to a lower energy state, emitting gamma rays as they do so. Second, the fast neutrons may collide with nuclei and transfer some of their energy. The now excited nuclei will return to their normal state by the emission of gamma rays. Many reactions of these two types occur before the bomb material is completely blown apart and therefore the resultant gamma rays are strongly absorbed. One notable exception is the absorption of the neutrons by nitrogen in the air, producing high energy gamma rays.

The third source of gamma rays is the radioactive decay of the fission products themselves which emit gamma rays. The activity of these fission products decays very rapidly at times immediately following a detonation, yet for a short time the activity is so relatively great that the gamma rays make a significant contribution to the total flux. Of course, the fission products are radioactive isotopes of varying half lives so that the decay is spread out over many years. Therefore, a time limit of one minute after detonation is chosen to distinguish between the instantaneous and delayed gamma rays. This is perhaps not so arbitrary as it may first appear. The fireball (containing most of the activity) rises with an average rate of ascent for the first minute, of about 250 feet per second. Thus, at the end of one minute the distance between the fireball and ground would result in a major attenuation of the gamma rays.

The instantaneous gamma exposure experienced from a nuclear detonation depends upon the distance (inverse square law) and the attenuation factors (generally the more dense is the air the greater is the attenuation). From past tests it is possible to construct curves of gamma exposures versus distances for a given yield shot, and then to scale to other yields. However, especially with higher yield detonations, this scaling factor changes more rapidly than does the ratio of yields. For example, going from a 1 to a 10-megaton air burst (a factor of 10), the scaling factor increases by about 35. This is because following the passage of the shock front there is a region of increased and sustained low air density where there is appreciably less attenuation of the gamma rays. A surface burst might be expected to produce a somewhat smaller gamma exposure at a given distance than an air burst. However, the possible reduction is not nearly so great as described for attenuation of thermal rays.

Table 2 presents estimates of the gamma exposures that might result from different yield air bursts.

At the time of the nuclear detonation neutrons are also emitted. These neutrally charged particles travel at less than the speed of light yet essentially all of them are received within a second after the burst. These neutrons have energies (speeds) covering a wide range but are relatively high as they leave the point of detonation. They

TABLE 2.—APPROXIMATE DISTANCES (MILES) FROM AN AIR BURST TO PRODUCE THE GAMMA EXPOSURES SHOWN

Yield (kilotons)	Gamma Exposures (Roentgens)		
	30	300	1,000
20	1.1	0.8	0.65
200	1.6	1.2	1.0
1,000	2.1	1.6	1.4
5,000	2.6	2.1	1.8
20,000	3.2	2.6	2.3

undergo collisions with nuclei of oxygen and nitrogen in the air and are thus slowed down. As their energies decrease into the thermal regions the probability of capture becomes greater and they are thus removed from the flux. Whereas, the total number of neutrons received from a detonation becomes less at greater distances, the energy spectrum remains fairly constant for appreciable distances, i.e., there is a reduction in energies in the higher region due to collisions with the air nuclei but at the same time the low speed neutrons are lost from the flux by capture.

The amount of *gamma* radiation received at a given distance can be scaled for other fission yields (within certain ranges), but the neutron flux depends greatly on the characteristics of the nuclear device. The materials that make up the device influence the extent of capture of fission neutrons. Also, thermonuclear reactions create significantly more neutrons per energy yield than does the fission process. Any single set of values of neutron flux versus distance would necessarily be only generalized.

The most meaningful expression of neutron exposure would be in terms of biological damage. It has been found that for a given unit of energy absorbed in the body, neutrons produce a greater biological damage than do gamma rays. The amount of this relative effectiveness depends upon the energy of the neutrons as well as the criterion of bodily damage selected, but for generalized whole-body effectiveness it is thought that 1.7 is a reasonable representative value for neutrons from a nuclear detonation. To place gamma and neutron radiation on a common basis in terms of biological damage, the unit of REM (Roentgen Equivalent Man) is used.

TABLE 3.—APPROXIMATE DISTANCES (MILES) FROM AN AIR BURST TO PRODUCE THE NEUTRON EXPOSURES SHOWN

Yield (kilotons)	Gamma Exposures (REM)		
	30	300	1,000
20	1.0	0.75	0.63
200	1.2	1.0	0.9
1,000	1.4	1.2	1.1
5,000	1.6	1.4	1.3
20,000	1.8	1.6	1.5

TABLE 4.—APPROXIMATE DISTANCE (MILES) FROM AN AIR BURST TO PRODUCE THE TOTAL NUCLEAR (GAMMA PLUS NEUTRONS) EXPOSURES SHOWN

Yield (kilotons)	Total Nuclear Exposures (REM)		
	30	300	1,000
20	1.2	0.81	0.65
200	1.7	1.2	1.1
1,000	2.1	1.6	1.4
5,000	2.6	2.0	1.8
20,000	3.3	2.5	2.2

Table 3 shows approximate neutron doses versus distances for varying yield bursts. Comparing Tables 2 and 3 it may be seen that for yields around 20 kilotons, the radiation exposures from gamma rays and neutrons are about equal but as the yields increase the doses from gamma rays substantially exceed those from the neutrons.

The total radiation dose received from the instantaneous nuclear radiations is the sum of the contribution from gamma rays and neutrons. Table 4 shows the approximate *total* nuclear radiation exposures versus distances from varying yield bursts. The 30-rem value was selected to represent an exposure that probably would produce no detectable damage to individuals so exposed; 300 rems might produce a small percentage of deaths; and 1000 rems would almost certainly cause death for all exposed individuals.

Table 4 indicates two important features of the doses from instantaneous nuclear radiations. One, a relatively small variation in distance from a nuclear detonation can make a very significant difference in the radiation dose received. For example, the ratio of distances from a burst where essentially little biological damage is incurred to where all exposed personnel might receive lethal doses is less than a factor of two. Secondly, the biological damage from the thermal radiation and of the blast wave probably would not only be equal or greater than that from nuclear radiation within the areas where the latter might be effective, but the thermal and blast effects extend to much greater distances. For example, at a distance of 3½ miles the total radiation exposure from even a 20-megaton burst would be unimportant,

yet the thermal exposure would be great enough to completely char any exposed skin and to ignite normal clothing, and the blast wave would undoubtedly destroy even reinforced concrete buildings.

III. PROTECTIVE MEASURES

The most obvious method of protection from thermal and nuclear radiations is the use of shielding materials. In the prevention of flash burns, a preferred type of clothing would be a two layer garment loosely draped, with the outer one being light colored. Opaque nonflammable materials between the observer and the burst would essentially eliminate the possibility of flash burns. In regions of relatively high thermal flux, however, the scattered thermal rays may constitute an additional hazard requiring allround protection.

This scattering effect is also true for gamma rays. Theoretically, it is not possible to reduce a gamma flux to zero, since these rays are exponentially absorbed, but of course it is possible to attenuate them to very low values. The energy spectra of the instantaneous gammas covers a wide range so that a single attenuation value cannot be strictly applied. However, in general the attenuation is roughly proportional to the density of the material. About eight inches of concrete or 12 inches of earth will reduce the gamma flux to 50 percent. An additional thickness of like amount would reduce the gamma radiation to 25 percent, etc.

The attenuation of neutrons is somewhat more complex. The fast neutrons require a material such as iron or barium for inelastic scattering which slows down the neutrons into moderate range. These must be further slowed by elements of low atomic weight, and finally captured. Water is one suitable material for these reactions. However, most neutron capture results in unstable nuclei which then emit gamma rays which must be attenuated. Concrete and damp earth are two materials that have reasonably good characteristics for both neutron and gamma attenuation.

There has been some consideration given to the feasibility of evasive action to reduce the instantaneous nuclear radiation dose. Whereas, the neutron exposure is received almost at once, the gamma dose is delivered at a slower rate especially for the higher yield burst. This is due to the events described before of the region of low air density following in the wake of the blast wave, where there is appreciably less attenuation of the gamma rays. However, an examination of Table 4 will indicate that instantaneous gamma plus neutron doses are effective only within 3 miles for even a 20-megaton burst. As suggested before, at this range the thermal radiation would be so great that even if one is sheltered from the flash effects, the scattered thermal radiation and hot gases would undoubtedly be lethal and the blast wave (which would arrive in a fraction of a second) would probably demolish reinforced concrete buildings.

TABLE 5.—DATA ON DELIVERY OF THERMAL ENERGY AND ARRIVAL OF BLAST WAVE FROM AN AIR BURST

Yield (kilotons)	Distance* (miles)	Approximate Time to Deliver One-Third of Total Thermal Energy (seconds)	Approximate Time of Arrival of Blast Wave (seconds)
20	1.4	0.17	5.2
200	3.8	0.54	15
1,000	8	1.2	32
5,000	15	2.7	60
20,000	28	5.4	116

* Distances selected represent areas of probable third-degree burns if the skin is exposed to the total thermal radiation. Roughly one-third of this total thermal energy would be expected to produce only first degree burns.

The rate of delivery of *thermal* radiation is likewise less for larger yield bursts. Since the thermal energy per unit area required to produce a first degree burn is roughly one-third that for a third degree burn, one way to evaluate the feasibility of evasive action is to estimate the time required to deliver one-third of that amount of thermal energy required to produce a third degree burn. Using those distances where degree burns might be experienced from different yield weapons if one is fully exposed, Table 5 was prepared. It may be seen that for the larger yield bursts there may be sufficient time for an effective evasive action. Of course, at lesser ranges for a given burst the *total* thermal energy will be greater, and one-third of this value would be expected to produce more

serious skin damage than first-degree burns.

The above evaluation is possible and desirable for planning purposes. However, in the event of an enemy attack such a deliberate and dispassionate analysis would not be possible even if the size and position of the burst were known. Despite the qualifications made above concerning the effectiveness of evasive action, if an actual detonation were to occur, the best course of action would be to move first and calculate afterwards.

FUNCTIONAL ORGANIZATION OF HUMAN BRAIN

There is a mirror of one's past in one's brain. Under certain circumstances a person may be possessed of two consciousnesses—one of the immediate surroundings and circumstances, and one of the surroundings and circumstances of something subconsciously remembered. The phenomenon amounts to a "doubling of consciousness." One state of awareness is just as vivid as the other. The two are not likely to be confused.

This condition is reported by Dr. Wilder Penfield, director of the Montreal Neurological Institute, in a paper published in the most recent annual report of the Smithsonian Institution. The condition arises unpredictably, Dr. Penfield reports, when the cerebral cortex that covers one of the temporal lobes of the brain is stimulated with a gentle electrical current applied through a wire needle during surgical operations. Such surgery on the cortex lying just above one ear is performed under local anesthesia for a certain type of epilepsy. The patient remains conscious and free from pain throughout because of local anesthesia. Here are some instances reported by Dr. Penfield:

> A young woman heard music when a certain point in the superior surface of the temporal cortex was stimulated. She said she heard an orchestra playing a song. The same song was forced into her consciousness over and over again by restimulation at the same spot. . . . She was quite sure each time that someone had turned on a gramophone in the operating room.
>
> A South African who was being operated upon cried out in great surprise that he heard his cousins talking, and he explained that he seemed to be there laughing with them although he knew he was really in the operating room in Montreal.
>
> There were many other examples of hearing music but always the patient heard a singing voice, a piano, an organ, or an orchestra, and sometimes he seemed to be present in the room or in church where he had heard it. What he heard and experienced was a single occasion recalled to him with a vividness that was much greater than anything he could summon voluntarily by effort of his will.
>
> If the individual was asked later to recall the song he might be able to sing it, but he might not be able to recall the circumstances of any one previous hearing. His later memory of the song was a generalization. On the other hand, the electrode had reproduced for him one single previous experience when he had heard the music and it awakened in him the emotion which that particular occasion had originally aroused in him.

Dr. Penfield advances a possible explanation of the phenomenon. The cortex of the superior and lateral surfaces of the lobe is an area to which no function has been ascribed previously. Another part of this lobe, however, is concerned with hearing, but not with sound recollection or interpretation.

Apparently every sensory experience—sight, sound, taste, smell, touch, and the like—is carried by the appropriate nerves to a specific part of the cortex. There it is coordinated with other sensory impressions to make up a total pattern of experience. Now, the temporal lobe observations indicate, this pattern, or appropriate parts of it, is laid down or recorded in the cells of the cortex as though in a sound moving picture. It remains there forever, although it may pass completely out of conscious memory. The path over the nerves, however, is permanently impressed in the cortex.

Now, Dr. Penfield holds, the cortex itself—supposedly the seat of intelligence in man and higher animals in whom it is enormously developed—is not primarily responsible for the existence of consciousness. This is a function of the higher circuits in the "old brain," the brain stem. In it lie the coordinating circuits of the so-called centrencephalic system—which is thoroughly developed in lower animals. Before there is awareness the patterns of nerve conduction in the cortex must be relayed to this old brain. Actually large parts of the cortex can be cut away without seriously disturbing consciousness, but this disappears very quickly when the brain stem, with its centrencephalic system, is injured or diseased.

In some way electrical stimulation of the temporal cortex reactivates one of the permanently recorded experience patterns and the nerve pathways leading to the "o!d brain" act as a mirror, a reflection of the former experience. Thus the doubled consciousness results.

Similar experiences have never been produced by stimulating other cortical areas. The function of photograph gallery is confined to the temporal area.

"It may be assumed then," says Dr. Penfield, "that in this area of cortex each successive conscious experience is laid down in a relatively permanent pattern of nerve-cell connections and records all those things of which a man is conscious at any given time. It is as though the cortex contained a continuous strip of cinematographic film, a strip that includes the waking record from childhood onward. . . . Presumably these patterns are no more than pathways of permanent facilitation through preexisting connections of many branching nerve cells. When the electrode is applied the current seems to follow again this pathway, slowly, steadily, while all other neighboring pathways are somehow closed."

SEMINOLE LEGENDS

Still relatively primitive, the Seminole of the Florida Everglades predict hurricanes as much as a month in advance. They have their own version of the great Flood of Noah and an even more curious creation legend in which the story of Cain and Abel is mixed incongruously with the Christian tradition. Punishment for crime is usually in the form of whipping administered by a relative. For murder the penalty can be death at the hands of the family of the offender, if it is inflicted within 5 days. Otherwise the slayer gets a respite until the next "Corn Dance," which may be several months away.

These are among the beliefs and customs of the Seminole related by Dr. Frances Densmore, late research associate of the Bureau of American Ethnology, in a publication on the music of these people recently issued by the Smithsonian Institution.

Ability of the Indians to predict disastrous storms far in advance puzzles weathermen. For instance, Dr. Densmore relates, the great hurricane in the fall of 1926, one of the worst ever to hit the area, was known to the Indians at least 4 days in advance. They were so certain of it that they persuaded the Indian agent to move all his charges to a safe place, and thus they were entirely prepared for the catastrophe. In the neighborhood of Miami the same storm was predicted 30 days in advance. "How know?" the prophet was asked. "Moon tell me," he replied.

The flood legend, as recorded by Dr. Densmore, is as follows:

> The earth was all covered with water, but before this happened a man made a big houseboat and many people stayed in it. After a while a bass dived down and brought up earth in his mouth . . . the man made that earth into a ball.
>
> The beaver cut the ball in two with his tail. The man threw half toward the north and half toward the south. The beaver made them into big countries. The one towards the south was made into Cuba. The man said: "Everybody stay inside 4 days and then the land will be dry." After 2 days the ivorybill wanted to get out and it got out. The buzzard wanted to get out too. These two came out. These birds still keep away from people. The dogs stayed with the people, as they do now, and the people stayed in the big houseboat 4 days. After 4 days the man let them all out. By that time a big country was dry and it was a good country.

More intriguing is the Cain and Abel story, doubtless an interpretation of early missionary accounts. The older brother was a tiller of the soil, the younger a shepherd. "Cain" slays "Abel" but afterward becomes strangely identified with the Christ figure, the villains being Spaniards.

ENTOMOLOGY.—*Type specimens of mosquitoes in the United States National Museum: VI, Miscellaneous genera, addenda, and summary.*[1]

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This is the final paper of this series, and after dealing with the genera not treated in the first five parts, we offer a few additions and corrections, and a tabulation of the genera and species treated.

The introductory remarks in the first paper of this series, particularly those on early, possibly questionable holotypes, also apply to this one. Following our treatment of nominal taxa in each genus, we list those in the collection based on unique specimens or for which holotypes were clearly designated.

Genus **Aedomyia** Theobald

Aedeomyia catasticta Knab, Ent. News **20:** 387. 1909.

Three female and four male syntypes of this species are in the collection. We select as lectotype a female labeled "Thru Miss Ludlow/Samal, Bataan, P. I./Type No. 12,627 U.S.N.M./*Aedeomyia catasticta* Knab."

Genus **Ayurakitia** Thurman

Ayurakitia griffithi Thurman, 1954. Holotype.

Genus **Culiseta** Felt

Theobaldia alaskaensis Ludlow, Can. Ent. **38:** 326. 1906.

The five female and one male syntypes of this species are in the collection under two different type numbers (3359 and 27807). We select as lectotype the male bearing the labels "Ft. Egbert, Eagle, Alaska, 2 June 06/Type No. 3359 U.S. N.M./*Theobaldia alaskaensis* Ludlow." The terminalia are mounted on slide no. 222.

Culiseta dugesi Dyar and Knab, Proc. Biol. Soc. Washington **19:** 134. 1906.

The five syntype females of this species are in the collection. We select as lectotype one bearing the labels "Guanajuato, Mex. 20 Jan 05/A. Duges Coll./Type No. 9962 U.S.N.M./*Culiseta dugesi* D & K. Type."

Culex dyari Coquillett, Journ. New York Ent. Soc. **10:** 192. 1902.

The three female and one male syntypes of this species are in the collection, all bearing the labels "Center Harbor, N. H./Collection Dr. H. G. Dyar/Type No. 6700 U.S.N.M." We select as lectotype the male, with terminalia unmounted.

Culiseta maccrackenae Dyar and Knab, Proc. Biol. Soc. Washington **19:** 134. 1906.

The one male and four female syntypes of this species are in the collection. We select as lectotype the male, labeled "L. S. Jr. U. Lot 30, Sub. 3/Stan.U.Cal. 23 Jun 1903/Type No. 9961 U.S.N.M./*Theobaldia annulata* Meig. California I. McC. Col." The terminalia are mounted on slide no. 221.

Culex melanurus Coquillett, Journ. New York Ent. Soc. **10:** 193. 1902.

This species was described from two females and two males. There are seven specimens in the collection from the type locality collected by Dyar but none of them bears a type label. Two specimens bear Coquillett's determination label and these, at least, are probably syntypic. We select as lectotype the male of these two, bearing the labels "Iss. VIII.2 #20/Center Harbor, N. H./Collection Dr. H. G. Dyar/See Slide No. 20/*melanurus*." The terminalia are on slide no. 20.

Culicella (*C.*) *parodites* Dyar, Mosquitoes of the Americas: 244. 1928.

The three male and one female syntypes of this species are in the collection. We select as lectotype the male, labeled "Saxesville, Wis. VI.23.09/B. K.

[1] Earlier papers of this series appeared in this JOURNAL **45:** 282–289. 1955; **46:** 213–228, 276–280. 1956; **47:** 42–59, 117–126. 1957.

[2] Studies upon which this paper is based were conducted under an exchange of funds from the Office of Naval Research (Biological Science Division) to the Smithsonian Institution. The opinions or assertions contained here are the private ones of the writers and are not to be construed as official or reflecting the views of the Navy Department or Naval Service at large.

Miller Coll./Slide 735/Type U.S.N.M." The slide bears the terminalia.

Culiseta siberiensis Ludlow, Ins. Insc. Mens. **7:** 151. 1919 [1920].

This species was described from 24 females collected in three localities in Siberia. Twenty-three of these are in the collection, and nine bear type labels. It is not possible to tell the type locality of any of these bearing the red type labels, since they are either unlabeled or have all three localities on the label. We select as lectotype a female labeled "Type No. 27808 U.S.N.M./*Culiseta siberiensis* Ludl. Mostovoi, Selenga, Verkhne Udinsk, Siberia Type (1)."

Holotypes, designated or unique:

Culex inornatus Williston, 1893.
Culiseta (Culicella) nipponica LaCasse and Yamaguti, 1950.

Genus **Deinocerites** Theobald

Dinomimetes epitedeus Knab, Journ. New York Ent. Soc. **15:** 120. 1907.

The two female and one male syntypes of this species are in the collection, all bearing the labels "Port Limon, C. R./Type No. 10291 U.S.N.M." We select as lectotype the male, bearing the additional labels, "No. 344a See F. Knab's Entom. Notes/See Slide No. 286." The terminalia are on the slide.

Deinocerites cancer var. *melanophylum* Dyar and Knab, Journ. New York Ent. Soc. **15:** 200, 1907.

The nine syntypes of this species are in the collection, each bearing the label "Type No. 10865 U.S.N.M." We select as lectotype a male, with the additional labels "213/Colon, Panama/Collected by August Busck/*Deinocerites melanophilum* [sic] D. & K. Type."

Deinocerites pseudes Dyar and Knab, Smithsonian Misc. Coll. **52:** 260. 1909.

The nine syntypes of this species are in the collection, each bearing the label "Type No. 12053 U.S.N.M." We select as lectotype a female, bearing the additional labels "378/Ancon, Canal Zone, Panama/A. H. Jennings Collector."

Dinanamesus spanius Dyar and Knab, Smithsonian Misc. Coll. **52:** 259. 1909.

The two syntypes of this species are in the collection. We select as lectotype the female, bearing the labels "69/A. H. Jennings Collector/Type No. 12052 U.S.N.M./*Dinanamesus spanius* D. & K. Type." Data for Jennings number 69 are, "Corazal, Panama, Dec. 11, 1907, from crab hole."

Deinocerites tetraspathus Dyar and Knab, Smithsonian Misc. Coll. **52:** 260. 1909.

The two syntype females are in the collection. We select as lectotype the one bearing the labels "Bluefields, Nicaragua/Type No. 12109 U.S. N.M./See Slide No. 472." The terminalia are mounted on the slide.

Deinocerites troglodytus Dyar and Knab, Smithsonian Misc. Coll. **52:** 260. 1909.

Eighteen of the original 20 specimens of this species are in the collection. Only one bears a type label, and this we consider the holotype. The labels on this female specimen are "Trinidad, W. I. June/Aug. Busck Collector/Type No. 12128 U.S.N.M."

Deinocerites monospathus Dyar, 1925. Holotype, unique.

Genus **Ficalbia** Theobald

Ludlowia minima Theobald, Can. Ent. **39:** 413. 1907.

The syntype pair of this species are in the collection. We select as lectotype the female, bearing the labels, "Type No. 27800 U.S.N.M./*Ludlowia minima* Ludlow. Cudarangan, Mindanao, P. I. January. Type C.S.L./Slide 56.III.1."

Holotypes, designated or unique:

Aedes clavirostris Stone and Bohart, 1944.
Ficalbia flavens King and Hoogstraal, 1946.
Oreillia luzonensis Ludlow, 1905.
Ficalbia modesta King and Hoogstraal, 1946.

Genus **Heizmannia** Ludlow

Heizmannia scintillans Ludlow, 1905. Holotype, unique.

Genus **Hodgesia** Theobald

Hodgesia ampyx Dyar, Ins. Insc. Mens. **8:** 176. 1920.

The two syntype females of this species are in the collection. Both are in poor condition, but we select as lectotype the better one of the two. It

bears the labels "Acc. No. 18399 Coll. of Agr. Univ. P. I./Type No. 23716 U.S.N.M./*Hodgesia. ampyx* Dyar. Type."

Hodgesia niveocaputis Ludlow, Psyche **18:** 130. 1911.

The five syntype females of this species are in the collection, each bearing the label "Type No. 27798 U.S.N.M." One only bears additional labels, and this we select as lectotype. The labels are "Wing slide/*Hodgesia niveocephala* [sic] Ludl. Fort Pikit, Mindanao, P. I. Type." The slide is in the collection.

Genus **Mansonia** Blanchard

Taeniorhynchus aureosquammatus Ludlow, Can. Ent. **4:** 234. 1909.

The collection contains five specimens labeled by Ludlow either as *Taeniorhynchus aureosquammatus* or *Oculeomyia ? aureosquammosa*, as well as a number of others with no labels. Only one bears a type label (unnumbered) and we select this as lectotype. This female bears the label "*Oculeomyia ? aureosquammosa* [sic] n. sp., Parang, Nov. 1908."

Mansonia chrysogona Knab, Ent. News **20:** 386. 1909.

The two female and one male syntypes of this species are in the collection. We select as lectotype the male, labeled "Parang, Mindanao 31. May 06/See Slide No. 488/Type No. 12,626 U.S. N.M." The terminalia are on the slide.

Taeniorhynchus coticula Dyar and Knab, Journ. New York Ent. Soc. **15:** 101. 1907.

The two syntype females of this species are in the collection bearing the labels "USDA No. 10417/Bocas d Toro, Pan. 25 Sept. 03/P. Osterhout Collector/Type No. 10281 U.S.N.M." We select as lectotype the better of these, bearing Dyar's determination label.

Mansonia (*Coquillettidia*) *diaeretus* Dyar, Ins. Insc. Mens. **8:** 181. 1920.

The two syntype females of this species are in the collection, each bearing the label, "Type No. 23721 U.S.N.M." We select the better of these as lectotype, bearing the labels "Los Banos, P. I. 5.III.1918/*Taeniorhynchus diaeretus* Dyar Type."

Mansonia humeralis Dyar and Knab, Ins. Insc. Mens. **4:** 65. 1916.

This species was described from females and eggs. The collection contains two original females but only one bears a type label and this we consider the holotype. The labels are "H.W.B.Moore See letter Feb. 8, 1916/*M. titillans* egg cluster in tube/Type No. 20366 U.S.N.M./*Mansonia humeralis* D. & K. Type."

Taeniorhynchus nigricans Coquillett, Proc. Ent. Soc. Washington **6:** 166. 1904.

The two syntype females of this species are in the collection, each bearing the labels "Panama Apr. 18, 04/J. W. Ross/Type No. 7943 U.S. N.M." We select as lectotype the better of the two, bearing Coquillett's determination label.

Taeniorhynchus pagei Ludlow, *in* Theobald, Monograph of the Culicidae **5:** 618. 1910.

The two female and one male syntypes of this species are in the collection. Two bear an unnumbered type label only. The third, a female, bears the additional label "*Taeniorhynchus pagei*, Parang, Mindanao, P. I. Oct. Page." The original material of *aureosquammatus* and *pagei* are largely unlabeled and mixed, but we think that this specimen can be justifiably selected as lectotype of *pagei*.

Holotypes, designated or unique:

Taeniorhynchus flaveolus Coquillett, 1906.
Mansonia hypocindyna Dyar, 1918.
Mansonia indubitans Dyar and Shannon, 1925.
Mansonia (*Mansonioides*) *marquesensis* Dyar, 1925 (terminalia only).
Culex ochropus Dyar and Knab, 1907.
Bancroftia persephassa Dyar and Knab, 1909.

Genus **Orthopodomyia** Theobald

Mansonia fascipes Coquillett, Proc. Ent. Soc. Washington **7:** 182. 1905.

The collection contains two females bearing the labels "No. 338b See F. Knab's Entom. notes/R. Aranjuez, Puntarenas, C. R./Cotype No. 8296 U.S.N.M." A third is the same except that the number is 338d. There are other specimens of the same series not labeled as type, so it is impossible to say which is the fourth syntype. We select as lectotype the female bearing the label in Coquillett's hand "*Mansonia terrens* Walk."

Orthopodomyia (*O.*) *nipponica* LaCasse and Yamaguti, Mosquito Fauna of Japan and Korea II: 264. 1948.

The syntypes of this species consisted of two females and one male reared from a single larval collection. One of each sex were said to have been sent to the Museum. The collection contains two of each sex bearing identical data but from the care in labeling it is quite evident which were the two syntypes. We select the female of these two as lectotype. The only label is "*Orthopodomyia nipponica* LaCasse and Yamaguti. Female, Kyoto, Honshu, 17 November 1948. 207th M.S.D."

Holotypes, designated or unique:

Orthopodomyia alba Baker, 1936.
Orthopodomyia californica Bohart, 1950.
Mansonia phyllozoa Dyar and Knab, 1907.
Culex signifer Coquillett, 1896.

Genus **Toxorhynchites** Theobald

Toxorhynchites argenteotarsis Ludlow, Can. Ent. **38:** 367. 1906.

Four of the five female syntypes of this species are in the collection. A fifth specimen bears an unnumbered type label and Ludlow's determination and type label, but it is from Corregidor and is therefore not one of the original specimens. Of the other four, one bears a red type label with no number, two bear type no. 10254, and one type no. 27784. The one without a number carries a type label in Ludlow's hand. Type no. 27784 bears no data so that only three bear original data, and we select as lectotype the one labeled by Ludlow "*Toxorhynchites argenteotarsis* Ludl. Margosatubig, Mindanao, P. I. June & July 1906. Type C.S.L./Type No.___ U.S.N.M."

Worcesteria grata Banks, Philippine Journ. Sci. **1:** 780. 1906.

The original description of this species states, "Types ♂ of and ♀. No. 6071 in Entomological Collection, Bureau of Science, Manila, P. I. There are 18 cotypes in the collection." We can assume that Banks was using "cotype" in the sense of "paratype", so that there were a pair of syntypes selected from the others to represent the species. All the material in the Bureau of Science Collection was destroyed so that these two "types" are lost. The National Museum collection has two males and one female of the series no. 6071 cotypes. We feel that since these are of the original series and are therefore syntypic, since no holotype was originally selected, and since these are probably the only original specimens in existence, we can legitimately select one of the males as lectotype. The labels on this specimen are "Acc. No. 6071 Lot. co-type Govt. Lab. Coll./Type No. 10255 U.S.N.M./*Worcesteria grata* Banks."

Megarhinus guadeloupensis Dyar and Knab, Smithsonian Misc. Coll. **48:** 254. 1906.

The two original specimens, a male and a female, are in the collection. Only one bears a type label and this female we consider the holotype. It bears the labels "79.1/Guadeloupe, W. I. July/Aug. Busck Collector/Type No. 9956 U.S. N.M./*Megarhinus guadeloupensis* D. & K."

Megarhinus haitiensis Dyar and Knab, Smithsonian Misc. Coll. **48:** 253. 1906.

The original female and three males of this species are in the collection, all labeled "S. Frncsco Mts. S Domingo W. I. Sept. 05/Aug. Busck Collector." Only one bears a type label and this female we consider the holotype. It bears the additional labels "134.1/Type No. 9955 U.S. N.M./*Megarhinus haitiensis* D. & K."

Megarhinus moctezuma Dyar and Knab, Smithsonian Misc. Coll. **48:** 251. 1906.

Of the original 16 males and 2 females of this species, two males are missing. Only one specimen bears a type label so this we consider the holotype. It bears the labels "No. 3380 See F. Knab's Entom. notes/R. Aranjuez, Puntarenas, C. R./Type No. 9953 U.S.N.M./*Megarhinus moctezuma* D. & K."

Megarhinus rutila Coquillett, Can. Ent. **28:** 44. 1896.

The original material was said to consist of three males and five females from North Carolina and Georgiana, Florida. In the collection are two specimens from Georgiana, Florida, and seven labeled only "Fla." and none from North Carolina. One specimen bears a type label and this we select as lectotype. This male bears the labels "Fla/Type No. 903 U.S.N.M./*Megarhinus rutilus* Coq."

Megarhinus septentrionalis Dyar and Knab, Smithsonian Misc. Coll. **48:** 249. 1906.

One only of the 24 original specimens bears a type label, and this we consider the holotype. The labels on this male are, "Woodstock, Va. iss 24 Aug. 04/F. C. Pratt Collector/Type No. 9952 U.S.N.M./*Megarhinus septentrionalis* D. & K."

Megarhinus superbus Dyar and Knab, Smithsonian Misc. Coll. **48:** 255. 1906.

We consider the holotype to be the single specimen bearing a type label. This male bears the labels "Trinidad, W. I./F. W. Urich Collector/16-9/Type No. 9957/*Megarhinus superbus* D. & K." The terminalia are mounted on a slide.

Megarhinus trinidadensis Dyar and Knab, Smithsonian Misc. Coll. **48:** 252. 1906.

One only of the five original specimens bears a type label and this female we consider the holotype. It bears the labels "Trinidad, W. I./F. W. Urich Collector/B3.2/Type No. 9954 U.S. N.M./*Megarhinus trinidadensis* D. & K."

Holotypes, designated or unique:

Megarhinus gigantulus Dyar and Shannon, 1925.
Megarhinus hypoptes Knab, 1907.
Megarhinus iris Knab, 1913.
Megarhinus lewaldii Ludlow, 1904.
Megarhinus nepenthis Dyar and Shannon, 1925.

Genus **Uranotaenia** Lynch Arribálzaga

Uranotaenia calosomata Dyar and Knab, Journ. New York Ent. Soc. **15:** 200. 1907.

The five syntypes, two females and three males, of this species are in the collection, three with type labels, two without. We select as lectotype a male bearing the labels "23.8/Tabernilla, Canal Zone, Panama/collected by August Busck/Type No. 10866 U.S.N.M." A portion of the larval skin of this specimen is mounted on a slide.

Uranotaenia clara Dyar and Shannon, Ins. Insc. Mens. **13:** 68. 1925.

The syntype pair of this species is in the collection. We select as lectotype the male, bearing the labels "2150/Type No. 28103 U.S.N.M./Ludlow Barracks, Mindanao, P. I." The terminalia are on slide no. 2150.

Uranotaenia coatzacoalcos Dyar and Knab, Journ. New York Ent. Soc. **14:** 186. 1906.

This species was described from the larva only, collected at Santa Lucrecia, Mexico. The only original material found consists of two larval head capsules and fragments of the rest of the skins. The material is so inadequate that there is no point in selecting a lectotype.

Uranotaenia cooki Root, Journ. Parasitol. **23:** 98. 1937.

Root selected one of each sex from a series of five specimens to be types of this species. These were supposedly deposited in the National Museum collection. All that we find in the collection is a slide labeled "*Uranotaenia cooki* Root (type) Port-au-Prince, Haiti, Feb. 11, 1932, Dr. S. S. Cook/Type No. 50375 U.S.N.M." This contains the fore leg, portion of another tarsus, and the terminalia. It is quite certain that this is the specimen figured by Root. We select this slide as lectotype.

Uranotaenia caeruleocephala var. *lateralis* Ludlow, Can. Ent. **37:** 385. 1905.

The four syntype females of this species are in the collection bearing either numbered or unnumbered type labels. We select as lectotype one bearing the labels "Type No. 27786 U.S.N.M./*Uranotaenia caeruleocephala* Theob. var. *lateralis* Lud. Cottabato, Mindanao, P. I. June. Type C.S.L."

Uranotaenia ludlowae Dyar and Shannon, Ins. Insc. Mens. **13:** 68. 1925.

Twenty of the original 22 syntype females of this species are in the collection. We select as lectotype one bearing the labels "Type No. 28077 U.S.N.M./Ludlow Barracks, Mindanao."

Uranotaenia urania Shannon and Del Ponte, Rev. Inst. Bact. **5:** 83. 1928.

The syntype pair of this species is in the collection. We select as lectotype the male, bearing the labels "Resistencia, Chaco 20.2.27/2355/*Uranotaenia urania* S. & D.P." The terminalia are mounted on slide no. 2355.

Holotypes, designated or unique:

Uranotaenia barnesi Belkin, 1953.
Uranotaenia basalis Howard, Dyar, and Knab, 1913.
Uranotaenia briseis Dyar, 1925.
Uranotaenia capitis Shannon and Del Ponte, 1928.
Uranotaenia civinskii Belkin, 1953.
Uranotaenia pulcherrima var. *elnora* Paterson and Shannon, 1927.
Uranotaenia fimbriata King and Hoogstraal 1947.
Uranotaenia hystera Dyar and Knab, 1913.
Uranotaenia incognita Galindo, Blanton, and Peyton, 1954.
Uranotaenia innotata Dyar and Shannon, 1925.
Uranotaenia nanseica Bohart and Ingram, 1946.

Uranotaenia neotibialis King and Hoogstraal, 1947.
Uranotaenia orthodoxa Dyar, 1921.
Uranotaenia paludosa Galindo, Blanton, and Peyton, 1954.
Pseudouranotaenia parangeneis Ludlow, 1909.
Uranotaenia setosa King and Hoogstraal, 1947.
Uranotaenia sexaueri Belkin, 1953.
Uranotaenia solomonis Belkin, 1953.
Uranotaenia stonei Bohart and Ingram, 1946.
Uranotaenia subtibioclada King and Hoogstraal, 1947.
Uranotaenia syntheta Dyar and Shannon, 1924.
Uranotaenia telmatophila Galindo, Blanton, and Peyton, 1954.
Uranotaenia tibioclada King and Hoogstraal, 1947.
Uranotaenia trapidoi Galindo, Blanton, and Peyton, 1954.
Pseudouranotaenia triangulata Ludlow, 1908.
Uranotaenia typhlosomata Dyar and Knab, 1907.
Uranotaenia wysockii Belkin, 1953.

Genus **Zeugnomyia** Leicester

Holotypes:

Zeugnomyia aguilari Baisas and Feliciano, 1953.
Zeugnomyia fajardoi Baisas and Feliciano, 1953.
Zeugnomyia lawtoni Baisas, 1946.

ADDITIONS AND CORRECTIONS, PARTS I TO V

In the first five parts of this series a few species were omitted for one reason or another, and a few errors were made and since discovered. We deal with these at the present time.

Aedes diantaeus Howard, Dyar, and Knab.

The name was first validated in vol. 2, fig. 167, of "Mosquitoes of North and Central America and the West Indies," 1913, not vol. 4, 1917, as given in Part II.

Aedes draconarius Dyar, Ins. Insc. Mens. **10:** 194, 1922.

This species was described from two females and four males, one pair being in the U. S. National Museum, and the rest returned to the Museum of Natural History in Paris. According to Dr. Séguy, the Paris Museum has two females, one labeled as type by Dyar, the other a "cotype" without type label. Since only one female was returned to Paris by Dyar it is probable that the "cotype" was not actually seen by Dyar. There are then three syntypes in existence, consisting of a pair of specimens in the U. S. National Museum entered in the type catalogue by Dyar under type No. 25765, and a female in the Paris Museum. We select as lectotype the female of the two syntypes in the U. S. National Museum. It bears the labels "St. Laurent du Maroni, Guyane fr. Dr. E. Brimont 1909, Institut Pasteur/Type No. 25765 U.S.N.M."

Aedes euiris Dyar, Ins. Insc. Mens. **10:** 193. 1922.

The three female syntypes of this species were distributed between the Paris Museum (2) and the U. S. National Museum, one of the former being labeled "cotype." Dr. Séguy informs us that the one labeled "cotype" by Dyar is in the Paris Museum, the second specimen not being found. We select as lectotype the female in the U. S. National Museum labeled "Colombia Dr. F. A. Miller/Type No. 25763 U.S.N.M./*Aedes euiris* Dyar Type."

Anopheles neivai Howard, Dyar, and Knab.

This name was first validated in vol. 2, pl. 41, fig. 8, and fig. 461, of "Mosquitoes of North and Central America and the West Indies," 1913, not vol. 4, 1917, as stated in Part III.

Aedes palustris var. *pricei* Dyar.

This was incorrectly placed alphabetically in Part II, p. 223. It should have come after *Culex pretans* on. p. 224.

Aedes (*Soperia*) *pseudodominicii* Komp, Proc. Ent. Soc. Washington **38:** 75. 1936.

The type of this species was to have been placed in the U. S. National Museum Collection but it has not been found and is probably lost.

Aedes (*Howardina*) *stenei* Thompson, 1956.

The holotype of this species has been placed in the collection since the publication of Part II.

SUMMARY

In a series of six papers we have treated the type material of 910 named specific, subspecific, or varietal taxa of mosquitoes in 27 genera. Of these there are 875 taxa for which either a holotype or a lectotype is in the U. S. National Museum collection.

The following alphabetical list of genera shows the part or parts of the series of papers in which each was treated.

Genus	*Part*
Aedeomyia	VI
Aedes	II, VI
Anopheles	III, VI
Armigeres	I
Ayurakitia	VI
Chagasia	III
Culex	IV
Culiseta	VI
Deinocerites	VI
Ficalbia	VI
Haemagogus	I
Heizmannia	VI
Hodgesia	VI
Limatus	V
Malaya	V
Mansonia	VI
Orthopodomyia	VI
Phoniomyia	V
Psorophora	I
Sabethes	V
Topomyia	V
Toxorhynchites	VI
Trichoprosopon	V
Tripteroides	V
Uranotaenia	VI
Wyeomyia	V
Zeugnomyia	VI

CRYSTAL CHEMISTRY OF TOOTH AND BONE MINERAL

Using the techniques of chemical crystallography, scientists at the National Bureau of Standards are developing new information on the nature of calcified tissue. The Bureau's dental research laboratory has synthesized pure single crystals of hydroxyapatite[1]—the prototype of the main mineral constituent in teeth and bone. Both the synthetic and naturally occurring apatites have been analyzed by X-ray diffraction and infrared absorption spectroscopy.[2] Results of the study may lead to a better understanding of the function of calcified tissue in the body and eventually perhaps to new methods of treating diseased teeth and bone.

The current investigations are being conducted by A. S. Posner, research associate, American Dental Association; A. F. Diorio, a guest worker from the Walter Reed Army Medical Center; and A. Perloff of the Bureau staff. The NBS constitution and microstructure laboratory is assisting in the work, and the National Institutes of Health and the Army Medical Center have cooperated on specific projects.

APATITE MINERALS

The apatites are the most abundant of the phosphate minerals. The name "apatite" was derived from the Greek word meaning "to deceive" since the mineral was often confused with others like aquamarine or amethyst. Pure hydroxyapatite is a chemical rarity having the formula $Ca_{10}(PO_4)_6(OH)_2$. However, the mineral known as hydroxyapatite always contains a certain portion of fluoride ions (F^-) replacing the hydroxyl ions (OH^-).

Previous analyses had shown that tooth mineral is some form of hydroxyapatite mixed with other phases. Thus the study of the calcified tissue in teeth ties in with that of the apatite family of minerals. Besides providing a better understanding of the structure and function of dental enamel, the data developed should be useful in a number of other fields including mineralogy, crystallography, basic chemistry, and physics.

The crystallographic studies at the Bureau indicate that the major constituent of tooth mineral may be a calcium-deficient hydroxyapatite[3]. Chemical analyses of sound human teeth show they contain less than 10 calcium atoms for every 6 atoms of phosphorus. In other words, there is not enough calcium to provide the 10Ca/6P ratio found in perfect hydroxyapatite. However, X-ray and index of refraction studies of teeth definitely indicate the presence of apatite. The evidence taken together suggests the presence in teeth of defect apatites in which some of the calcium ions are missing from certain struc-

[1] For further technical details, see *Preparation of pure hydroxyapatite crystals*, by A. Perloff and A. S. Posner, Science **48:** 383. 1956.

[2] *Infrared study of the carbonate in bone, teeth, and fracolite*, by A. S. Posner and G. Duckaerts, Experientia **10:** 424. 1954.

[3] *Apatites deficient in divalent cations*, by A. S. Posner and A. Perloff, Journ Research Nat. Bur. Stand. **58:** 279. 1957. RP 2761.

tural positions and electrical neutrality is achieved by the inclusion of hydrogen ions in the proper amount somewhere in the structure. This concept may lead to an explanation for the differences in reactivity (i.e., solubility, hardness, caries resistance, etc.) of one tooth as compared to another.

SYNTHESIS OF PURE HYDROXYAPATITE

In order to obtain basic information on the purer forms of the apatite minerals, a standard pure apatite was synthesized at the Bureau in a hydrothermal bomb. The crystals were examined by X-ray diffraction, infrared spectroscopy, and other techniques. The synthesis procedure involves hydrolyzing monetite ($CaHPO_4$) to hydroxyapatite in a closed system. The materials —0.1 gram of monetite and 10 ml of water —are placed in a platinum-lined hydrothermal bomb and subjected to a temperature of 300°C for 10 days. During this time the system had an internal pressure of about 1250 psi due to the vapor pressure of the saturated steam. Crystals were formed ranging up to 0.3 mm in length with negligible quantities of impurities. It should eventually be possible to produce even larger crystals which can be used as standard reference samples in X-ray diffraction studies of all apatite minerals.

DEFECT APATITES

By controlling the pH at which the apatite is precipitated it is possible to produce calcium-deficient or "defect" hydroxyapatite. A number of compounds of this sort were produced ranging from the calcium-phosphorus ratio of pure hydroxyapatite (10Ca/6P) to a low Ca/P ratio of 8.2/6.0. In general the Ca/P ratio of apatitic calcified tissue (bone, teeth, etc.) lies below the value expected of pure hydroxyapatite.

Since a structure from which cations are removed has an excess of negative charges, it was postulated that the proper number of hydrogen ions enter the hydroxyapatite structure, not directly in calcium positions, but as hydrogen bonds between orthophosphate oxygens. Recent infrared absorption studies show that pure hydroxyapatite does not contain such hydrogen bonding while synthetic defect apatites and calcified tissue do.

Some of the chemical properties of these defect apatites are different from those of pure hydroxyapatite. An example directly applicable to biochemistry is the solubility. The Bureau in cooperation with NIH has demonstrated that when the synthetic low-calcium apatites react with calcium acetate, the solubility in weak lactic acid is reduced by about 35 percent.[4] Studies with rat molar teeth yielded similar results. This may provide a mechanism whereby chemical treatment may produce a more stable tooth structure.

CARBONATE

The carbonate found in tooth and bone mineral is of the order of 3 percent carbon dioxide by weight, but its function in calcified tissue remains uncertain. Also, its exact crystallographic placement in the tooth structure has been debated. For example, is the carbonate substituted in the apatite crystal, or admixed or adsorbed as a separate phase? In order to investigate this problem, a number of techniques were employed at the Bureau including X-ray diffraction, infrared absorption spectroscopy, electron microscopy, and preferential solubility studies. It was concluded that carbonate occurs as admixed or adsorbed calcite ($CaCO_3$) or magnesite ($MgCO_3$). Since the particles are not detected by X-ray diffraction or electron microscopy, it is suggested that the carbonate particles are too small to be seen by these techniques.

SMALL PARTICLE SIZE

Small crystal size is a striking feature of the chemically precipitated basic calcium phosphates, precipitation being the mechanism by which bone is produced in the blood serum. Dentin and enamel mineral and synthetically precipitated apatites have average crystal diameters in the range below 1000A and may be studied by the line broadening methods of X-ray diffraction.

These studies indicate an average crystalline diameter ranging from 150 to 300A for bone, dentin, and the precipitated apatites. Particle size distribution curves obtained from line broadening experiments show that steam-autoclaved bone contains crystals ranging from 50 to 1000A in diameter with about 80 percent appearing in the 300A region.

[4] *Effect of calcium treatment on solubility and calcium uptake of synthetic hydroxyapatite and rat molar enamel*, by R. C. LIKINS, A. S. POSNER, and A. C. STEERE, paper presented at meeting of International Association for Dental Research, Atlantic City, N. J., March 1957.

These measurements are biologically significant since they confirm the large specific surface apparent in the apatite of calcified tissue and underline the importance of surface reactions in the functioning of bone and teeth. If indeed the apatite in teeth and bones are defect apatites, the properties of the biological apatites will change with increasing exposure to ions that can fill the defects. Cooperative studies between NIH and NBS are in progress on the application of the defect apatite theory to explain aging in bone and teeth mineral and the general function of apatite in these systems.

SOLAR FURNACE

A solar furnace that generates temperatures two-thirds as hot as the surface of the sun has recently been acquired by the National Bureau of Standards as a new research facility in the high-temperature field. Bureau scientists are now using the furnace to produce temperatures up to 3500°C to melt refractory materials in a controlled environment free of contaminating agents. Investigations at high temperatures carried out with the aid of the solar furnace should result in better temperature-resistant materials to withstand the extreme conditions found in atomic reactors, aircraft engines, and guided missiles.

New or improved refractories—that is, materials that can withstand very high temperatures for long periods of time—are continually being developed by industry, and new applications are being found for these products. Consequently, knowledge of the properties of these materials—melting points, strength at high temperatures, etc.—is urgently needed. Investigations in this field should supply valuable engineering information to the user of refractories. High-temperature tungsten arc or carbon resistor furnaces have commonly been employed in the past for such studies, but with the disadvantage that the crucibles, electrodes, or resistors contaminate the reaction and give false indications. However, in a solar furnace, the material itself can be its own crucible, with consequent freedom from contamination.

The Bureau's solar furnace was converted from a surplus Army searchlight with a 5-foot diameter parabolic mirror. It collects the sun's rays and focuses them into an intensely hot spot only one-fourth inch in diameter. Heating occurs only at this small spot, and the experiment is carried out here. This area can be isolated by closed glass tubing, which can be evacuated or filled with gas of the experimenter's choice. The glass enclosure is not affected by the sun's rays since the image of the sun is unfocused where the light passes through the enclosure and no local heating of the glass results.

The curved mirror faces a flat mirror, about 8 feet square, which is directed at the sun and reflects the light into the solar furnace. This large, flat mirror, called a heliostat, is attached to a search ight mount so that it can be turned to follow the sun through the sky as the earth turns on its axis. An assembly of photocells with appropriate electronic equipment controls the heliostat driving mechanism in response to the sun's apparent motion.

Besides study of the properties of refractory materials, the solar furnace can be used in the "zone refining" of oxides of zirconium, thorium, or uranium to produce extremely pure samples of those compounds. By means of the solar furnace it might even be possible to grow single crystals of these and similar materials for laboratory studies.